

1 A Reappraisal: Natural History of Amniote Reproductive Modes In Light of Comparative
2 Evolutionary Genomics
3 Maggs X^{*1}
4 ¹ Richard Gilder Graduate School at The American Museum of Natural History; 200 Central
5 Park West, New York, NY 10024
6 maggs_x@outlook.com; 973-534-9937; ORCID: 0000-0002-6660-7599

7 **Abstract**

8

9 There is a current lack of consensus on the ancestral parity mode, oviparity (egg-laying) and
10 viviparity (live-birth), of amniotes and squamates (snakes and lizards). How transitions between
11 parity modes occur at the genomic level has primary importance on how science conceptualizes
12 the origin of amniotes, and highly variable parity modes in Squamata. Within the context of
13 interdisciplinary literature—medical, poultry science, reproductive biology, and evolutionary
14 biology—I review the genomics and physiology of five broad processes expected to change
15 during transitions between parity modes: eggshell formation, embryonic retention, placentation,
16 calcium transport, and maternal-fetal immune dynamics. Throughout, I offer alternative
17 perspectives and testable hypotheses regarding proximate causes of parity mode evolution in
18 amniotes and squamates. Should viviparity have evolved early in the history of Lepidosauria, I
19 offer the basal cap hypothesis as a proximate explanation. The framework of this hypothesis can
20 be extended to amniotes to infer their ancestral state. I also provide a mechanism through which
21 squamates may reverse back to oviparity with no intermediate stages. Furthermore, I
22 contextualize the maternal-fetal immune dynamics in light of modern medical understanding that
23 embryos are not analogous to allografts (e.g., organ transplants). Overall, this review grounds
24 itself in the historical literature while offering a modern perspective on a subject that has
25 fascinated scientists for centuries—the origin of amniotes. I encourage the scientific community
26 to utilize this as a resource in comparative genomics studies, embrace the complexity of the
27 system, and challenge new hypotheses proposed.

28

29 *Key Words:* reproductive mode, parity modes, oviparity, squamates, eggshell deposition,
30 embryonic retention, embryonic calcium transport, maternal-fetal interface, comparative
31 evolutionary physiology.

32

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90 **I. Introduction**

91

92 A reappraisal is needed for the conceptual framework used to research the evolution of
93 oviparity (egg-laying) and viviparity (live-birth) in amniotes (birds, non-avian reptiles, and
94 mammals). Squamates (snakes and lizards) are unique amongst amniotes because they have
95 highly variable parity modes (Figure 1). Beginning with the first phylogenetic analyses on the
96 subject, a warm-blooded scientific disagreement has persisted over the labile nature of
97 evolutionary transitions between parity modes (Blackburn, 1999, 2015; de Fraipont, Clobert &
98 Barbault, 1996; Griffith et al., 2015; Harrington & Reeder, 2017; Lee & Shine, 1998; Pyron,
99 2015; Pyron & Burbrink, 2014; Recknagel et al., 2018, 2021b). A growing number of
100 transcriptomic and genomic studies analyzing the molecular underpinnings of reproductive mode
101 evolution in squamates (e. g., Brandley et al. 2012; Cornetti et al. 2018; Gao et al. 2019; Griffith et al.
102 2016, 2017; Foster et al. 2020, 2022; Recknagel et al. 2021a; Yurchenko et al. 2020; Xie et al. 2022) and
103 recent advances on the ancestral state of amniotes and dinosaurs contribute to this discussion (Jiang et
104 al., 2023; Norell et al., 2020). It is prudent to acknowledge that the relative difficulty of changing
105 phenotypes cannot be determined from morphology alone or unidentified physiological
106 mechanisms. At least theoretically, any phenotypic change could be facilitated by simple
107 genomic changes (e.g., a single nucleotide polymorphism) or any combination of multi-omic
108 changes to any number of loci. As research begins to reveal the molecular networks involved
109 with parity mode evolution, it is important to avoid bias that could be introduced by assumptions
110 on the feasibility of transitions. Through synthesis of modern and historical research on amniote
111 reproduction, this review aims to provide greater context for hypotheses testing ancestral states
112 of parity modes in amniotes and squamates.

113 The earliest estimates predicted that viviparity evolved independently between 90-100
114 times in squamates (Blackburn, 1982, 1985, 1992). These estimates assumed that oviparity was
115 the ancestral state and, based on the theoretical grounds of Dollo's law, that reversals back to
116 oviparity should be exceedingly rare (Blackburn, 1992; Fitch, 1970; Neill, 1964; Tinkle &
117 Gibbons, 1977). An intermediate phenotype of re-evolving an eggshell has been considered as
118 physiologically unviable, preventing reversals (Blackburn, 1995; Griffith et al., 2015). This was
119 demonstrated when experimentally induced extended egg retention in phrynosomatid lizards
120 resulted in adverse embryonic development attributed to impeded gas exchange imposed by the
121 eggshell (Mathies & Andrews, 1999, 2000; Parker & Andrews, 2006). However, this result may
122 be clade-specific.

123 Intermediate phenotypes as fitness valleys assumes 1) eggshells inherently impede gas-
124 exchange and 2) that an eggshell must re-evolve before a reversal back to oviparity is possible
125 (Griffith et al., 2015). Contrarily, eggshells are considered a component of the placenta in
126 viviparous Rough Earth Snakes, *Haldea striatula*, and in viviparous reproductively bimodal
127 European Common Lizards, *Zootoca vivipara* and Yellow-bellied Three-toed Skinks, *Saiphos*
128 *equalis* (Stewart, 2013). Additionally, *Saiphos equalis* is a reproductively bimodal skink that has
129 an oviparous population with incubation times as short as 5 days, thus embryos spend significant
130 time in utero with an eggshell (Smith et al., 2001). Another surprising example of eggshells
131 being compatible with full embryonic development includes a report of a captive tortoise that
132 retained viable eggs until the hatching stage (Kuchling & Hofmeyr, 2022).

133 Several studies predict early origins of viviparity in squamates (Jiang et al., 2023; Pyron
134 & Burbrink, 2014) and reversals back to oviparity (de Fraipont et al., 1996; Fenwick et al., 2011;
135 Harrington & Reeder, 2017; Lee & Shine, 1998; Pyron & Burbrink; Recknagel et al., 2018).

136 *Saiphos equalis* proved the possibility of reversals when a viviparous individual oviposited an
137 egg prior to birthing fully developed young within the same litter (Laird et al., 2019). The
138 unusual absence of an egg-tooth in oviparous Arabian Sand Boas, *Eryx jayakari* (Lynch &
139 Wagner, 2010; Staub & Emberton, 2002) serves as additional biological evidence of a reversal,
140 though this has been challenged (Griffith et al., 2015). Importantly, extended embryonic
141 retention, characteristic of oviparous squamates compared to birds, is viewed as compatible with
142 labile transitions (Jiang et al., 2023). Current expectations are that oviparity may re-evolve more
143 easily in squamate lineages that recently evolved viviparity and which have not lost specific
144 avian eggshell-matrix proteins (Laird et al., 2019; Xie et al., 2022).

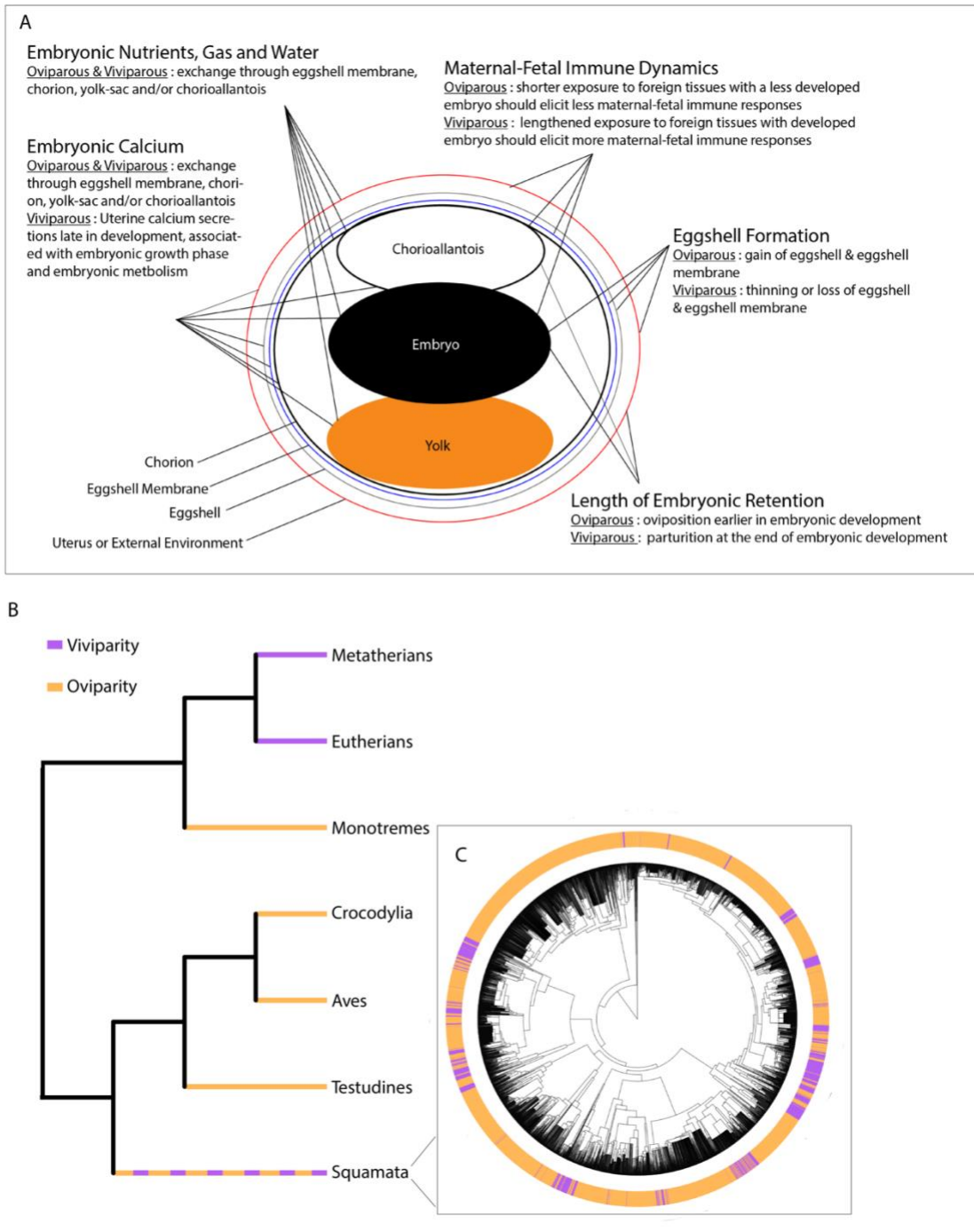
145 Discoveries of viviparity in ancient amniotes are numerous, dating back to the Early
146 Permian (Chuliver, Scanferla & Smith, 2022; Motani et al., 2014; Piñeiro et al., 2012; Jian et al.,
147 2023). A viviparous most recent common ancestor of amniotes is not unreasonable. Most
148 compelling is the report that *Ikechosaurus sp.*, a basal archosauromorph, reached an articulated
149 stage of embryonic development inside of a parchment shelled egg (Jiang et al., 2023). This
150 brings support to the extended embryonic retention model (EER) (Hubrecht, 1910). The EER
151 model postulates that amniote fetal membranes arose through pressure to support exposure to
152 maternal-fetal tissues during extended embryonic retention (see Laurin et al., 2005 for a
153 summary of earlier ancestral reconstructions of EER). It serves as an alternative to the widely
154 accepted model that eggs laid on land prompted the evolution of fetal membranes to retain water
155 with an eggshell that facilitated gas exchange (Romer, 1957). The discovery that hard-shelled
156 eggs most likely evolved three times in dinosaurs, deriving from a soft-shelled ancestor (Norell
157 et al., 2020) is consistent with the EER. As Romer (1957) phrased it “It was the egg which came
158 ashore first; the adult followed”. This is also consistent with EER, which is compatible with both

159 oviparity and viviparity (Laurin, 2005; Mossman 1987). Throughout this review, considering
160 viviparity as the most extreme form of extended embryonic retention, I hope to persuade readers
161 to consider the EER model in a new light. I lay this out through testable hypotheses on the
162 ancestral eggshell of amniotes and Lepidosaurians (section III.3), a phylogenetic framework to infer
163 ancestral states based on mechanisms of maternal-embryonic calcium provisioning (section V.2),
164 and various discussions on what evolutionary comparative genomics reveals about amniote
165 reproductive mode evolution.

166 Regardless of disagreements, it is sensible to equate the EER with pre-adaptations of the
167 egg to land. Without substantial amounts of water, converting yolk nutrients to somatic tissue is
168 impossible (Thompson & Speake, 2003). Water is the primary resource provisioned by the
169 mother of viviparous squamates and it is stored in extraembryonic membranes (Lourdais et al.,
170 2015). For example, water and gas exchange are associated with poor chorioallantoic blood flow
171 (Wootton et al., 1977). In oviparous *Saiphos equalis*, a species with extended embryonic
172 retention, the chorioallantois thickens to support embryonic growth in late development (Parker
173 et al., 2010). Thus, if the amniote egg evolved via the EER model, it may have prompted the
174 origin of extraembryonic membranes of amniotes. This translates to an egg washed ashore that
175 has already evolved to withstand dryer environments.

176 Although models that restrict parity mode evolution to be unidirectional (from oviparity
177 to viviparity) are shown to be poor fits for squamates (Pyron & Burbrink; Recknagel et al.,
178 2021b), there is resistance to the proposition that viviparity originated early in Squamata (e.g.
179 Griffith et al., 2015). The most recent ancestral state reconstruction, built from biomineralization
180 and parity mode data across 80 extinct and extant amniotes using a single structured Markov
181 model, inferred viviparity with extended embryonic retention in the first amniotes and in the

182 most recent common ancestor of Lepidosauurs (squamates and sphenodontia) (Jiang et al., 2023).
183 However, maximum parsimony, and alternative maximum likelihood and Bayesian
184 reconstructions did not estimate viviparity in the most recent common ancestor of Lepidosauurs
185 (Jiang et al., 2023). A testable hypothesis regarding a molecular mechanism that may have
186 supported a transition to viviparity at the base of squamates and extended embryonic retention at
187 the base of amniotes will help conclude these decades long debates.



188

189 **Figure 1:** Schematic demonstrating (A) the anticipated processes that change during transitions
 190 between oviparity and viviparity, and the organs associated with those changes. Lines from the
 191 process to different organs indicate the organs expected to be involved with the evolutionary
 192 shift between oviparous and viviparous phenotypes. (B) relationships between major amniote

193 clades and their associated reproductive mode, and (C) the variation of reproductive modes
194 across squamates. The squamate phylogeny is adapted from Pyron et al., (2016) and reproductive
195 modes of squamate species from Pyron & Burbrink (2014).

196

197 The ecological drivers of parity mode evolution are beyond the scope of this review.
198 However, it is generally proposed that viviparity increases protection from adverse
199 environmental conditions (Ma et al., 2018; Pincheira-Donoso et al., 2017), and a general trend
200 that supports this is the higher frequency of viviparous squamates, relative to oviparous,
201 observed at increasing distances from the equator. The cold-climate hypothesis suggests that
202 viviparity is an adaptation to cold climates, and this is generally accepted by the scientific
203 community (e.g. Ma et al., 2018; Zimin et al., 2022). Consistent with the cold-climate
204 hypothesis, a recent study that utilized 65 million years of global paleoclimate data, squamate
205 phylogeny and parity data for over 3,000 taxa showed that persistent, stable cold climates are
206 correlated with transitions to viviparity (Recknagel et al., 2021b). Less focus has been on the
207 adaptive nature of oviparity. Compared to viviparity, oviparity is associated with higher
208 fecundity and lessened maternal investment (Recknagel et al., 2019).

209 With a deep review of interdisciplinary literature across amniotes and associated
210 supplementary materials, I explore genomic and physiological features of gestation and
211 gravidity, including those that could be exploited to support labile shifts, ancestral viviparous
212 states in amniotes and squamates, and those that may facilitate or impede reversals. Potentially of
213 most interest, I propose the framework of the basal cap hypothesis to help elucidate the ancestral
214 parity modes of squamates and amniotes (section III.3). It details how squamates may have
215 transitioned to viviparity (an extreme form of extended embryonic retention) early in their

216 evolutionary history. After much consideration, I advocate for using squamates as a model to
217 understand the ancestral state of the amniote egg. Future work should consider this thoughtfully
218 and embrace the complexity of the system. I hope this manuscript serves as a foundation for
219 further research on the evolutionary history of the amniote egg and reproductive mode evolution.

220

221 *(1) Terminology*

222 I use the conventional definition of viviparity as retention of eggs until the stage when the
223 embryo is fully developed (Blackburn & Stewart, 2021; van Dyke et al., 2014). Oviparity is
224 defined by eggs that develop outside the mother. I use the terms gravidity and gestation to
225 describe the period of internal retention of the embryo in oviparous and viviparous taxa,
226 respectively. Vertebrate placentas are conventionally defined by apposition of maternal and fetal
227 tissues. It is accepted that all viviparous squamates have a chorioallantoic placenta under this
228 definition (Blackburn & Stewart, 2021; Stewart & Blackburn, 1988). The avian chorioallantoic
229 membrane and mammalian chorioallantoic placenta are homologous (Metcalf & Stock, 1993). I
230 sometimes refer to this organ as the chorioallantoic tissue to describe it for both parity modes.
231 Oviposition refers to the process and act of egg-laying, while parturition refers to the process and
232 act of giving birth to live-young. Partition refers to both oviposition and parturition (Blackburn,
233 1992; Smith, 1975).

234

235 *(1) Main five physiological changes of parity mode transitions*

236 Several physiological features are expected to change during transitions between
237 oviparity and viviparity (Figure 1). I break this down into five physiological features (hereafter
238 Main Five)—1) length of embryonic retention (Murphy & Thompson, 2011; Packard et al.,

239 1977)—only viviparous mothers retain the embryo for the entirety of development; 2) eggshell
240 formation (Heulin et al., 2005; Packard et al., 1977; van Dyke et al., 2014)—viviparous embryos
241 generally do not have an eggshell; 3) placental development for maternal-fetal exchange of
242 required water, gas and/or nutrients (Blackburn, 1992, 2015; Thompson et al., 2000; Thompson
243 & Speake, 2006); 4) embryonic calcium provisioning (Packard et al., 1985; Shadrix et al., 1994;
244 Thompson & Speake, 2006)—sources of embryonic calcium and timing of uterine calcium
245 secretions generally differs between oviparous and viviparous reproduction; 5) maternal-fetal
246 immune dynamics (e.g., Graham et al., 2011; Hendrawan et al., 2017; Foster et al., 2020)—
247 viviparous reproduction is associated with maternal and embryonic exposure to foreign tissues,
248 which is likely to require enhanced regulation of maternal-fetal immune systems.

249

250 **II. Length of Embryonic Retention**

251

252 Viviparous amniotes retain the embryo until it is fully developed, but oviparous amniotes
253 retain the embryo for a fraction of that time. Rather than using precocious hatching and
254 parturition (PH&P), like that of opossums and early viviparous mammals (Wagner et al., 2014),
255 squamates evolve viviparity through extended egg retention (García-Collazo et al., 2012; Shine,
256 1983). Thus, processes affecting the length of embryonic retention are expected to change to
257 support transitions between parity modes (van Dyke et al., 2014).

258

259(1) *Parturition & oviposition*

260 The genes and hormones involved with initiating and ending gestation may provide insights
261 into the tools squamates can co-opt to change the length of embryonic retention during parity

262 mode transitions. Parturition terminates embryonic retention. Parturition can be divided into four
263 parts (Terzidou, 2007; Vannuccini et al., 2016)—quiescence (Phase 0), activation (Phase 1),
264 stimulation (Phase 2) and involution (Phase 3). In eutherian mammals, several processes
265 contribute to the initiation and termination of gestation including inflammation (Challis et al.,
266 2009; Hansen et al., 2017), maternal recognition of pregnancy (MRP), mechanical stretch of
267 uterine tissues (Sooranna et al., 2004; Shynlova et al., 2008), and fluctuating concentrations of
268 corticotropin-releasing hormone, progesterone, and estrogen (Challis et al., 2000; Condon et al.,
269 2004; Shaw & Renfree, 2001).

270

271 (i) *Quiescence & sustained progesterone production in reproductive tissues*

272 Extended embryonic retention could be achieved by triggering mechanisms that extend
273 uterine quiescence, inactivity of the uterus. Inhibition of myometrial contractions through
274 sustained progesterone production supports quiescence across different viviparous amniotes
275 (Bazer, 1992; Casey & MacDonald, 1997; Fergusson & Bradshaw, 1991; Ilicic et al., 2017;
276 Murphy & Thompson, 2011; Putnam et al., 1991; Soloff et al., 2011). The corpus luteum (or
277 plurally called corpora lutea), a transient progesterone-producing organ, produces progesterone
278 during gestation. Extended lifespan of the corpus luteum likely aided the evolution of viviparity
279 in mammals (Amoroso, 1968; Callard et al., 1992; Stouffer & Hennebold, 2015). Thus, early
280 research on squamate viviparity also explored the influence of corpus luteum lifespan. The
281 lifespan of corpora lutea associates with oviparous egg retention and oviposition (Diaz, Alonso-
282 Gomez & Delgado, 1994; Fox & Guillette 1987; Jones & Guillette 1982). Eggshell formation in
283 oviparous Whiptail lizards, *Cnemidophorus uniparens*, is even disrupted by experimental
284 removal of corpora lutea (Cuellar, 1979). The lifespan of corpora lutea do not consistently

285 correlate with length of embryonic retention in viviparous squamates like it does in mammals
286 (Albergotti & Guillette, 2011; Callard et al., 1992).

287 Maternal recognition of pregnancy (MRP) refers to the early signaling of the embryo to
288 prevent luteolysis (Thatcher, Meyer, & Danet-Desnoyers, 1995), degradation of the corpus
289 luteum. Luteolysis occurs in the absence of pregnancy. MRP enables continued progesterone
290 production by the corpus luteum to support uterine quiescence during early gestation. An
291 independent evolution of MRP is reported for Macropodidae, a lineage of marsupial mammals
292 (Freyer, Zeller, & Renfree, 2003), and endometrial recognition of pregnancy is recognized in the
293 opossum (Griffith et al., 2019). MRP has not been explicitly studied in squamates. However,
294 MRP likely happens in squamates, given that corpora lutea do not get degraded in the earliest
295 stages of gravidity/gestation in oviparous or viviparous squamates (Callard et al., 1992;
296 Albergotti & Guillette, 2011).

297 Different genes are signaled by embryos for MRP across mammals. Human chorionic
298 gonadotropin hormone (hCG) establishes MRP (Ross, 1979; Behrman et al., 1993; Duncan,
299 McNeilly, & Illingworth, 1998; Duncan, 2000; Ticconi et al., 2007). In pigs, MRP is
300 hypothesized to be triggered by collaborative signaling of estradiol (E2) and prostaglandins
301 (PGs) (Geisert et al., 2023). Similarly, glycoproteins, estradiol and prostaglandin E2 (PGE2)
302 have been implicated in signaling MRP in horses (Klein & Troedsson, 2011; Klein, 2016). In
303 ruminants, embryonic signaling of IFN- τ establishes MRP (Bazer, 2013; Bazer, Spencer & Ott,
304 1997; Thatcher et al., 1995). During gestation in the uterus of viviparous African Ocellated
305 skinks, *Chalcides ocellatus*, four receptors for interferon alpha, beta, omega, and gamma are
306 differentially expressed but no expression of IFN- τ was detected compared to non-gestational
307 uterine tissue (Brandley et al., 2012). I was unable to find expression patterns of MRP signaling

308 homologs in other squamate reproductive tissues. Should MRP occur in squamates, it may be
309 signaled by genes that are clade-specific, like in mammals. This makes comparatively evaluating
310 the influence of MRP on the evolution of viviparity an interesting avenue for future research.

311 The evolution of viviparous extended embryonic retention may be sufficiently supported by
312 maintenance of chorioallantoic progesterone production coupled with eggshell loss (Griffith,
313 Brandley et al., 2017). This theory may be broadly applicable across amniotes given that the
314 most recent common ancestor of amniotes likely had a chorioallantois with an endocrine
315 function (Griffith, Brandley et al., 2017). Following death of the corpus luteum during gestation,
316 placental progesterone production supports extended embryonic retention in eutherian mammals
317 (Castracane & Goldzieher, 1986; Ellinwood et al., 1989; Nakajima et al., 1991; Rothchild, 2003;
318 Spencer & Bazer, 2004). Viviparous Italian Three-toed Skinks, *Chalcides chalcides*, shift to
319 chorioallantoic progesterone production following degradation of corpora lutea during gestation
320 (Guarino et al., 1998). The placenta of viviparous Southern Snow Skinks, *Carinascincus*
321 *microlepidotus*, produces minimal progesterone but has a strong capacity to convert
322 pregnenolone to progesterone (Girling & Jones, 2003). Whereas all genes involved with a known
323 biosynthesis pathway for progesterone production are expressed in the placenta of horses, *Equus*
324 *caballus*, only some of these genes were detected in the chorioallantois of chickens, *Gallus*
325 *gallus*, viviparous Southern Grass Skinks, *Pseudemoia entrecasteauxii*, and oviparous and
326 viviparous Southeastern Sliders, *Lerista bougainvillii* (Griffith, Brandley et al., 2017). Thus, if
327 chorioallantoic progesterone production has supported multiple origins of viviparity in amniotes,
328 it is not evidenced by a conserved ancestral gene expression pattern for the biosynthesis of
329 progesterone (Griffith, Brandley et al., 2017). Nonetheless, parity trait genes in a reproductively

330 bimodal lizard, *Zootoca vivipara*, are associated with progesterone-binding functions (Recknagel
331 et al., 2021a)—highlighting the role of progesterone in squamate reproduction.

332 Other female reproductive tissues in squamates express genes involved with progesterone
333 biosynthesis—StAR-related lipid transfer domain protein 3 (*StARD3*) and hydroxy-delta-5-
334 steroid dehydrogenase (*HSD3B1*). *STARD3* is significantly upregulated in the uterine tissue
335 during pregnancy in viviparous African Ocellated skinks, *Chalcides ocellatus*, along with
336 significant differential expression of seven paralogs (Brandley et al., 2012). While *StARD3* is
337 expressed during gestation in *Zootoca vivipara*, it is not significant differentially expressed
338 compared to oviparous counterparts; *HSD3B1*, on the other hand, is significantly upregulated
339 during mid-gestation (Recknagel et al., 2021a). Compared to non-gestational samples, *HSD3B1*
340 is significantly upregulated in the uterus during early and late gestation in viviparous individuals
341 of reproductively bimodal *Saiphos equalis* (Foster et al., 2020). Oviparous individuals from the
342 same species did not exhibit this expression pattern (Foster et al., 2020). Activity of *HSD3B1*
343 was detected in the mucosal epithelium of oviparous Eastern Garden Lizards, *Calotes versicolor*
344 (Kumari et al., 1992), and in the uterine glands of oviparous Keeled Indian Mabuya, *Eutropis*
345 *carinata* (Mundkur & Sarkar, 1982). Other genes involved with the biosynthesis of progesterone
346 (e.g., steroidogenic acute regulatory protein or cytochrome-P450-family-11-subfamily-A-
347 polypeptide-1) serve as further candidates for exploring the relationship between organ-specific
348 patterns of progesterone production and the evolution of extended embryonic retention in
349 viviparous squamates.

350 For progesterone to prevent myometrial contractions and support quiescence, there must be
351 progesterone receptors (PGRs) in the uterus (Mesiano et al., 2011; Young et al., 2011). In
352 humans, progesterone responsiveness is related to specific ratios of PGRs, *PR-A* and *PR-B*, in

353 myometrial cells (Young et al., 2011). Minimal research exists on PGR expression in squamate
354 reproductive tissues. One study found that in the uterus of the yolk-sac in viviparous Southern
355 Grass Skinks, *Pseudemoia entrecasteauxii*, one progesterone receptor, *PGRMC2*, is upregulated
356 compared to non-gestational uterine tissue (Griffith et al., 2016); Another progesterone receptor,
357 *PGR*, is downregulated in the uterus of the chorioallantoic placenta and yolk sac placenta
358 compared to non-gestational uterine tissue (Griffith et al., 2016). Downregulation of both *PGR*
359 and *PGRMC2* in the uterus during gestation was detected in viviparous *Chalcides ocellatus*
360 (Brandley et al., 2012). While *PGR* is differentially expressed at mid-gestation in viviparous
361 individuals compared to oviparous, *PGRMC1* and *PGRMC2* are not differentially expressed
362 (Recknagel et al., 2021a). However, admixture mapping revealed three SNPs most highly
363 associated with gestation length in *Zootoca vivipara* are located in close proximity to *PGRMC1*
364 (Recknagel et al, 2021a). Measuring expression of PGRs and their ratios in uteruses of
365 oviparous and viviparous squamates will help elucidate the receptors needed to support
366 progesterone responsiveness in squamate uteruses and their relationship to extended embryonic
367 retention.

368

369 (ii) *Activation & progesterone withdrawal*

370 The activation stage of parturition is marked by the withdrawal, or functional withdrawal, of
371 progesterone leading to an estrogen dominated response during the next state, stimulation
372 (Bakker, Pierce, & Myers, 2017; Fergusson & Bradshaw, 1991). Progesterone may withdraw in
373 response to environmental stimuli in reptiles during parturition (Shine & Guillette, 1988). In
374 mammals, activation is marked by increasing concentrations of corticotropin-releasing hormone
375 and contraction associated proteins (CAPs) including connexin-43, prostaglandins, oxytocin

376 receptors, prostanoid receptors and cell signaling proteins (Bakker et al., 2017; Ilicic et al., 2017;
377 Leadon et al., 1982; Pashen & Allen, 1979; Whittle et al., 2000). Pro-inflammatory cytokines
378 and chemokines, prostaglandin synthase-2 (*COX-2*, also referred to as *PTGS2*), and NF-κB also
379 influence activation in mammals (Christiaens et al., 2008; Lappas et al., 2002; Lappas & Rice,
380 2007; Lindström & Bennett, 2005; Olson, 2003; Terzidou, 2007).

381 Some similar patterns are associated with oviposition in birds. In chickens, *Gallus gallus*,
382 prostaglandin F (PGF) concentrations increase in the hours leading up to oviposition (Takahashi
383 et al., 2004). Experimental injection of oxytocin and arginine vasotocin (AVT), similar
384 neurohypophyseal peptides, revealed that uterine tissues of chickens, *Gallus gallus*, maintain
385 responsiveness to oxytocin but are more sensitive toward arginine vasotocin (Ewy, 1970).
386 Murphy & Thompson (2011) provide a rather exhaustive list of resources on progesterone and
387 estrogen assays across oviparous and viviparous squamates. Future research should consider
388 exploring parallels between mechanisms of activation in mammals and squamates. Any process
389 that can trigger or stall activation should lead to extended embryonic retention.

390

391 (iii) *Stimulation & electrical gradients, inflammation, and hormonal regulation*

392 Mechanical stretch, electrical gradients, inflammatory processes, and hormonal regulation
393 contribute to stimulation, the phase when contractions, cervical ripening and dilation occur.
394 Stimulation involves contributions from maternal and fetal tissues. As early as 460 BC there was
395 uncertainty over the proportional influence of mother or fetus on the initiation of parturition.
396 Hippocrates proposed that the fetus initiates parturition by pushing its feet on the fundus of the
397 uterus. Although the reality is not so cartoonish, mechanical stretch of the uterus from the

398 growing embryo plays a role in parturition (Lefebvre et al., 1995; Tamizian & Arulkumaran,
399 2004; Wray et al., 2015).

400 Physical stretching of the uterus causes an influx of calcium and sodium, altering the action
401 potential and enabling contractions (Kao & McCullough, 1975). Calcium further activates
402 voltage gated calcium channels on myometrial cell membranes, enhancing the influx of calcium
403 ions, mediating the force and speed of myometrial contractility (Arrowsmith & Wray, 2014;
404 Wray et al., 2015). The influence of uterine overdistention on partition in birds and non-avian
405 reptiles has not yet been examined, to my knowledge. However, differentially expressed genes
406 functionally enriched the GO term for “voltage-gated calcium channel activity” in uterine tissues
407 during gravidity and gestation in *Saiphos equalis* (Foster et al., 2020). A uterine response to
408 overdistention is among the many possible explanations for this. It may be important to consider
409 the influence of uterine overdistention on squamate parity mode transitions, because should
410 bioelectrical responses to uterine overdistention be a common feature of vertebrate parturition,
411 lessened distention may be a hurdle to reverse back to oviparity. Uterine overdistention may
412 influence parturition by triggering an “inflammatory pulse” that activates further myometrial
413 contractility, which leads to preterm birth in primates (Adams Waldorf et al., 2015).

414 During parturition, there is an influx of uterine and embryonic pro-inflammatory genes and
415 immune cells (Adams Waldorf et al., 2015; Charpigny et al., 2003; Mesiano et al., 2002; Park et
416 al., 2005). Uterine contractions in humans involve actions of prostaglandins (PGs), oxytocin,
417 corticotropin-releasing hormone, cytokines, and neutrophils (Adams Waldorf et al., 2015; De
418 Rensis et al., 2012; Olson & Hertelendy, 1983; Park et al., 2005; Sykes et al., 2014; Terzidou,
419 2007).

420 The cycling concentrations of a neuropeptide, corticotropin-releasing hormone (CRH),
421 supports parturition in humans. This has been compared to a biological clock that is initiated at
422 early stages of gestation (Lockwood, 2004; McLean & Smith, 2001). Increased production of
423 CRH facilitates parturition by interacting with CRH receptors, CRH-R1 and CRH-R2, which are
424 suggested to promote myometrial relaxation or contractility, respectively (Hillhouse &
425 Grammatopoulos, 2001). Altered regulation, phenotype or function of hormones that function as
426 biological clocks, like CRH, may have a particularly strong influence on evolutionary changes to
427 length of embryonic retention, a trait inherently related to time.

428 Placental CRH production has only been identified in primates thus far (Challis et al., 2005;
429 Emanuel et al., 1994; Florio et al., 2002; Hillhouse & Grammatopoulos, 2001; Karteris et al.,
430 1998; Mendelson, 2009; Robinson et al., 1989). Placental CRH production may, therefore, be
431 unique to primates. However, the amino acid sequence of CRH is highly conserved in vertebrates
432 (Noy et al., 2017), indicating there is a possibility for shared function across diverse taxa. Like
433 CRH cycling in mammals, timely fluctuations of AVT stimulates uterine contractions, enables
434 oviposition in birds, turtles, and lizards (Ewy, 1970; Fergusson & Bradshaw, 1991; Guillette Jr &
435 Jones, 1980; Jones et al., 1987; Rzasa, 1978; Wu et al., 2019).

436 Prostaglandin E₂ (PGE₂) and prostaglandin F_{2α} (PGF_{2α}) influence, respectively, uterine
437 contractions and cervical relaxation for partition across many amniotes including humans, *Homo*
438 *sapiens* (Terzidou, 2007), domestic pigs (De Rensis et al. 2012), domestic chickens (Hertelendy
439 et al., 1974; Olson et al., 1986), and Loggerhead Sea turtles (Guillette et al., 1991). Injections of
440 PGF_{2α} and PGE₂ induce parturition in viviparous Yarrow's Spiny lizards, *Sceloporus jarrovi*, and
441 Raukawa geckos, *Woodworthia maculatus* (Cree & Guillette, 1991; Guillette et al., 1992).
442 However, no injected dosages of PGF_{2α} or PGE₂ induced oviposition in oviparous Collard

443 lizards, *Crotaphytus collaris*, Eastern Fence lizards, *Sceloporus undulatus*, Six-lined
444 racerunners, *Aspidoscelis sexlineatus*, or Striped Plateau lizards, *Sceloporus virgatus* (Guillette et
445 al., 1991). It is interesting that injections of $\text{PGF}_{2\alpha}$ and PGE_2 induced parturition in viviparous
446 lizards but did not induce oviposition in oviparous lizards studied. Given this, it is plausible that
447 regulatory or functional changes to $\text{PGF}_{2\alpha}$ and/or PGE_2 in squamates could facilitate changes to
448 the length of embryonic retention to support transitions between reproductive modes. However,
449 induction of parturition with $\text{PGF}_{2\alpha}$ in viviparous *Woodworthia maculatus* only worked with
450 pre-treatment of β -adrenoceptor (Cree & Guillette, 1991).

451 $\text{PGF}_{2\alpha}$ decreases progesterone concentrations during stimulation (De Rensis et al., 2012). In
452 humans, biosynthesis of PGs is driven largely by the enzyme cyclooxygenase (*COX*)-2 rather
453 than *COX-1* (i.e., prostaglandin synthase-2 and -1) (Slater et al., 1995, 1999). This helps
454 maintain the decreased progesterone/estrogen ratio of stimulation. In ovariectomized viviparous
455 Garter snakes, *Thamnophis*, increased estrogen stimulated thickness of uterine epithelial cells
456 and glandular activity, whereas administration of progesterone had little influence on uterine
457 histology (Mead et al., 1981). Uterine pig models revealed that estrogen stimulates involuntary
458 contraction and relaxation (peristalsis) of the uterus (Mueller et al., 2006).

459 The softening of the cervix is important during the stimulation stage of parturition. A
460 hormone related to insulin, *relaxin*, promotes myometrial softening in humans, *Homo sapiens*,
461 domestic pigs, and turtles (Mercado-Simmen et al., 1982; Sorbera et al., 1988; Weiss &
462 Goldsmith, 2001). The cervix also gets softer by actions of PGE_2 . PGE_2 activates pro-
463 inflammatory cytokines, interleukin (IL)-8 and tumor necrosis factor (TNF)- α , which activates
464 the collagenases and matrix metalloproteinases for cervical softening (Bakker et al., 2017). This
465 causes a positive feedback loop between IL-8 and PGE_2 synthesis (Denison et al., 1998;

466 Denison, Calder & Kelly, 1999; Terzidou, 2007; Li et al., 2010). Upregulated of IL-8 is also
467 promoted by the protein complex NF-kB during parturition in humans (Elliott, 2001). Similar
468 patterns were observed during parturition in mice and baboons (Mendelson & Condon, 2005;
469 Mendelson, 2009).

470 A few studies focus on the role of cytokines on squamate reproduction but not explicitly
471 during oviposition or parturition (Hendrawan et al., 2017; Paulesu et al., 1995, 2005, 2008).
472 Some studies detected expression of cytokines during late gestation (Foster et al., 2020; Gao et
473 al., 2019; Recknagel et al., 2021a). TNF- α related activity was only detected at this time in
474 viviparous Tussock Cool-skinks, *Pseudemoia entrecasteauxii*, which were found to
475 downregulate TNF- α induced proteins (*TNFAIP6* and *TNFAIP8L2*) in the ‘uterus of the
476 chorioallantoic placenta’ and *TNFAIP6*, *TNFAIP1*, and *TNFAIP2* in the ‘uterus of the yolk-sac
477 placenta’ compared to not gestational uterine tissues (Griffith et al., 2016). Activity of TNF- α in
478 reproductive tissues during gestation in viviparous Italian Three-toed skinks, *Chalcides*
479 *chalcides*, and reproductively bimodal European common lizards, *Zootoca vivipara*, was
480 associated with maternal-fetal immune dynamics (Paulesu et al., 1995, 2005, 2008; Hendrawan
481 et al., 2017).

482 Altered expression or phenotype of contractility agonists, oxytocin receptors and estrogen
483 receptors, and contractility antagonists, progesterone receptors and β -adrenergic receptors
484 (Ravanos et al., 2015) may also change the length of embryonic retention to support transitions
485 between parity modes. Differences in length of embryonic retention in oviparous and viviparous
486 agamas, *Phrynocephalus przewalskii* and *Phrynocephalus vlangalii*, appears to be driven by
487 regulatory differences of prostaglandins, *COX-2*, an AVT receptor (*MTR*), β -adrenergic receptors,
488 and estrogen receptors. During oviposition, *P. przewalskii*, exhibited the following: promotion of

489 contractions through downregulation of β -adrenergic receptor (*ADRB2*), and upregulation of
490 *COX-2* and prostaglandin, and absent (potentially lost) expression of two estrogen receptors
491 (*ESR1* and *ESR2*) and the AVT receptor, *MTR* (Gao et al., 2019). During the stage of gestation
492 corresponding to oviposition, viviparous sister-species, *P. vlangalii*, exhibited the following
493 alternate pattern: inhibition of contractions caused by upregulation of *ADRB2* and
494 downregulation of two estrogen receptors (*ESR1*, *ESR2*), *MTR*, *COX-2*, and prostaglandin (Gao
495 et al., 2019). Some viviparous squamates, *Saiphos equalis*, *Chalcides ocellatus*, and *Pseudemoia*
496 *entrecasteauxii*, share some of these expression patterns (*COX-2*, *MTR*, and *ADRB*, respectively)
497 thought to be involved with extended embryonic retention in viviparous *P. vlangalii* (Brandley et
498 al., 2012; Foster et al., 2020; Gao et al., 2019; Griffith et al., 2016); and *ADRB2* is upregulated at
499 mid-gestation in viviparous *Zootoca vivipara* compared to oviparous counterpart (Recknagel et
500 al., 2021a). Overexpressed genes in viviparous uterine tissues of *Zootoca vivipara* also
501 functionally enriched pathways for beta 1 and beta 2 adrenergic receptor signaling pathways
502 (Recknagel et al., 2021a). This study, which compared uterine expression profiles during
503 gestation across viviparous species of squamates, rodents, canines, ungulates, and humans,
504 concluded that shared regulatory networks are recruited to support viviparity (Reckangel et al.,
505 2021a).

506 Recently, in humans, the only Classical Major Histocompatibility Antigen (C-MHC)
507 expressed by trophoblasts (specialized placental cells) was associated with parturition when it
508 was discovered that HLA-C is significantly increased during laboring term and preterm placentas
509 compared to non-laboring placentas (Hackmon et al., 2017). The authors suggested a mechanism
510 where fetal HLA-C open conformers on the placenta provoke inflammation of maternal tissues,
511 leading to parturition (Hackmon et al., 2017). Expression of MHC alloantigens, foreign antigens

512 to the host, by fetal cells is also associated with parturition in cows and horses (Benedictusa,
513 Koets & Ruttena, 2015; Davies et al., 2004; Joosten et al., 1991; Rapacz-Leonard et al., 2018).
514 Around one month prior to parturition in cows, endometrial epithelium thins and eventually
515 disappears completely, putting the antigen-presenting trophoblasts (Adams et al., 2007) in
516 contact with maternal connective tissue of the endometrium (Podhalicz-Dzięgielewska et al.,
517 2000). Fetal MHC alloantigens are proposed to promote the loosening of maternal and fetal
518 tissues (Benedictusa et al., 2015). MHC molecules are expressed during gestation in some
519 squamates (Murphy, Thompson & Belov, 2009) but their role in oviposition or parturition has
520 not yet been considered to my knowledge. Identifying the presence or absence of MHC
521 alloantigens on embryonic tissues before and during parition across more diverse taxa may
522 reveal how ubiquitous the influence of embryonic MHC molecules is on this.

523 Involution (phase 3) occurs after the embryo(s) is released. In eutherian involution, the
524 placenta detaches, and the uterus shrinks. This is supported by actions of prostaglandins
525 (Husslein, 1984) and oxytocin (Terzidou, 2007). It seems unlikely for processes of involution to
526 be related to evolutionary changes to the length of embryonic retention.

527

528 (2) *Unique qualities of oviposition & parturition in Sauropsids*

529 The physiology of avian oviposition is dependent on a circadian schedule (Williams, 2012).
530 A general model of an “open period”, when eggs are laid are separated by “laying gaps”
531 (Williams, 2012). Chicken ovulation and oviposition cycles leave an 8-hour open period where
532 luteinizing hormone (LH) and progesterone surge, initiating ovulation and continuing the cycle.
533 At the extreme, the ancient murrelet, *Synthliboramphus antiquus*, oviposits a two-egg clutch on
534 seven-day intervals (Williams, 2012). Longer laying intervals have been associated with longer

535 intervals between initiation of yolk development (Astheimer & Grau, 1990). Differing from
536 birds, oviparous squamates retain eggs longer than the ovarian cycle (Tinkle & Gibbons, 1977).
537 This suggests that oviparous squamates may rely on different molecular mechanisms to support
538 oviposition than birds.

539 Non-avian reptiles are unique in that they are the only ectothermic amniotes. This makes
540 them uniquely reliant on temperature for embryonic retention and associated embryonic
541 signaling to indicate the stage of embryonic development. Additionally unique, gemales are the
542 heterogametic sex in several squamates, leading some research to suggest chromosome linkage
543 evolution may increase the speed of evolution in genes associated with gestation length
544 (Recknagel et al., 2021a). Admixture mapping, made possible by the natural hybridization of
545 oviparous and viviparous populations of *Zootoca vivipara*, revealed 439 candidate genes
546 associated with embryonic retention (Recknagel et al., 2021a). Eleven of these genes were also
547 associated with eggshell traits (Recknagel et al., 2021a)—underscoring the pleiotropic roles of
548 some genes putatively involved in squamate parity mode evolution.

549

550(3) *Pre-term birth & embryonic retention mechanisms*

551 The literature on pre-term birth may be a fruitful avenue of research to inform understanding
552 on the evolutionary genomics of embryonic retention length. Slower increases of CRH (Ellis et
553 al., 2002) and higher expression of Neurokinin B, for example, are associated with pre-term birth
554 in humans (Torricelli et al., 2007). Injections of RU486, a progesterone receptor (PGR)
555 antagonist, promoted pre-term labor in rhesus macaques but the progression of physiological
556 activity differed from normal parturition (Haluska et al., 1987). Examining homologs of genes
557 involved with human pre-term birth in squamates may provide further candidates for genes that

558 could impact the length of embryonic retention in squamates. Some evolutionary studies are
559 taking implications of pre-term birth into account. For example, a comparative evolutionary
560 transcriptomics study across therians, monotremes, squamates, and an amphibian recently
561 associated *HAND2* with preterm birth in Eutherian mammals (Marinić et al., 2021).

562 In humans, pregnancy loss from infection follows distorted ratios of immune factors at the
563 maternal-fetal interface (Arenas-Hernandez et al., 2016; Chaturvedi et al., 2015; Chattopadhyay
564 et al., 2010). Future research on the evolution of lengthened embryonic retention to support
565 viviparity may benefit from exploring ratios of immune cells in the uterus and embryonic tissues
566 during term and pre-term pregnancy in squamates. I direct researchers to the literature on the
567 reptile immune system and immune cell ratios at the maternal fetal interface during term and pre-
568 term mammalian pregnancy for further exploration (Yang et al., 2019; Zimmerman, 2010, 2020).

569

570(4) *Discussion & future directions—embryonic retention and parity mode evolution*

571 The physiological processes involved with the start of gestation (maternal recognition of
572 pregnancy) and the end of gestation (parturition) in birds and mammals provide insights into the
573 genes and hormones squamates may co-opt to alter length of embryonic retention during
574 transitions between parity modes. Unsurprisingly, hormones like estrogen and progesterone, play
575 important roles in parturition across amniotes. Further processes to be examined in squamates
576 include signaling of homologous genes for MRP, placental progesterone production, novel
577 pathways for biosynthesis of progesterone, the role of beta 1 and beta 2 adrenergic receptor
578 signaling pathways, fluctuating ratios of progesterone receptors, the lifespan of the corpus
579 luteum across a broader range of taxa, production and circulation of homologs for AVT and
580 CRH or other similarly structured genes, expression of fetal alloantigens and inflammatory

581 cytokines in utero, and the influence of uterine overdistention on contractions. Regarding
582 squamate parity mode transitions, the role of uterine overdistention in mammalian parturition
583 suggests a lack of uterine overdistention may be one hurdle for reversals back to oviparity.
584 Understanding the evolutionary physiology and genomics of embryonic retention in oviparous
585 and viviparous squamates will benefit from focused attention on reproductively bimodal species
586 (Whittington et al., 2022) and from genomics/physiological research across more taxa that vary
587 in reproductive modes.

588

589 **III. Eggshell Formation**

590

591 Oviparous amniotic embryos develop within an eggshell that is at least partially
592 mineralized, whereas viviparous embryos generally do not. Primarily, the eggshell serves as
593 physical protection and calcium reserve (Stewart & Ecy 2010; Stewart et al., 2009). The
594 eggshell matrix contains immune properties and pores that enable gas exchange and water uptake
595 (Packard et al., 1982). Evolutionary transitions between parity modes therefore requires changes
596 to the process of eggshell formation. The history of research on the evolutionary morphology of
597 the amniote egg is important for future comparative research (Blackburn & Stewart, 2021). Some
598 have suggested that the amniote eggshell originated multiple times (Aoki, 1993).

599 Birds have hard calcareous eggshells. Other than two lineages of geckos with hard shells,
600 oviparous squamates have parchment-shelled eggs with a thin layer of calcium deposits on the
601 outer surface of the shell membrane (Blackburn & Stewart, 2021; Choi et al., 2018).
602 Monotremata (egg-laying mammals) have an eggshell but far less has been documented about its
603 structure compared to other amniotes (Legendre et al., 2022). The structure and physiological

604 mechanisms involved with eggshell calcification are most well resolved in birds (Choi et al.,
605 2018; Francesch et al., 1997; Jonchère et al., 2010, 2012; Rose-Martel, Du, & Hincke, 2012).
606 Eggshell deposition in tuatara and squamates differs dramatically (Choi et al., 2018). Viviparous
607 squamates lack an eggshell, absorb the eggshell during gestation, or have a thin layer of calcium
608 deposits.

609 The earliest records of amniote eggshells have features characteristics of Archelosaur
610 eggshells, including the mammillary layer (Stein et al., 2019; Legendre et al., 2022). Recent
611 reconstructions are consistent with a thin eggshell in ancestral dinosaurs (Norell et al., 2020;
612 Stein et al., 2019). It is important to consider that the semi-rigid shells of Lepidosaur and
613 testudines are not homologous (Legendre et al., 2022); the microstructure of Archelosauria
614 (birds, crocodiles, turtles and dinosaurs) and Lepidosaur eggshells are remarkably different (Choi
615 et al., 2018); and recent reconstructions of the composition and ultrastructure of dinosaur
616 eggshells revealed that calcified hard eggshell of dinosaurs originated three times (Norell et al.,
617 2020). In the remainder of this section, I consider how structural, mineral,
618 genomic/transcriptomic, and proteomic information on amniote eggshells can inform scientific
619 understanding of the ancestral eggshell of amniotes and Lepidosaur.

620 The genetic drivers of eggshell formation are not resolved in squamates. Two oviparous
621 lizards, *Lerista bougainvillii* and *Lampropholis guichenoti*, differentially express either zero or
622 two genes, respectively, in utero in non-gravid vs gravid comparisons (Griffith et al., 2016).
623 However, this study only measured gene expression at one developmental stage, making it
624 difficult to infer if regulatory changes influence eggshell formation. Nonetheless, oviparous
625 *Saiphos equalis* and *Phrynocephalus przewalskii* have extensive differential expression during
626 gravidity (Foster et al., 2020; Gao et al 2019). It is interesting to see drastically different uterine

627 gene expression profiles associated with oviparity, given that shared genes are recruited to the
628 uterus to support viviparity across diverse amniotes (Recknagel et al., 2021a). Under the
629 assumption that conserved traits should be accompanied with more similar gene expression
630 profiles than convergent traits, uterine gene expression profiles in themselves currently reveal
631 more conserved regulatory networks in utero for squamate viviparity than oviparity.

632 Some genetically determined traits are known to be evolutionarily labile in squamates, like
633 venom and limb reduction (Camaiti et al., 2021; Sites et al., 2011). In *Saiphos equalis*, shell
634 characteristics of facultatively partitioned oviparous and viviparous embryos are similar, leading
635 authors to infer that both parity modes utilize the same machinery to produce egg coverings
636 (Laird et al., 2019). In this species, environmental influences on gestation length, rather than
637 genetic influences on eggshell thickness, may play a more dominant role in parity mode
638 evolution (Laird et al., 2019). In *Zootoca vivipara*, Recknagel et al. (2021a) identified 38
639 candidate genes associated with eggshell traits and concluded that the genetic architecture of
640 eggshell traits is simpler than that of gestation length.

641

642 (1) *Mineral composition of eggshells*

643 The different mineral compositions of eggshells across amniotes may provide insight into the
644 differing physiological conditions and evolutionary histories under which they are formed (Table
645 1). Taxa use a polymorph of calcium carbonate—calcite, aragonite or vaterite—to develop the
646 eggshell (Hincke et al., 2012). Amorphous calcium carbonate (ACC) is a transient non-
647 crystalline precursor phase of calcite and aragonite that is important for many calcification
648 processes in invertebrates (Hincke et al., 2012). It was recently shown to control avian eggshell
649 mineralization (Rodríguez-Navarro et al., 2015).

650 In birds, the organic components of uterine fluid promote the formation of calcite
 651 (Hernández-Hernández, Gomez-Morales et al., 2008; Hernández-Hernández, Rodriguez, et al.,
 652 2008; Hernández-Hernández, Vidal et al., 2008). Most amniotes use this polymorph (Hernández-
 653 Hernández, Gomez-Morales et al., 2008; Hernández-Hernández, Rodriguez, et al., 2008;
 654 Legendre et al., 2022). However, turtle eggshells are predominately developed with aragonite
 655 (Choi et al., 2022; Mikhailov, 1997). The eggshell of most squamates consists of an inner fibrous
 656 protein layer overlain by calcium carbonate that can be a single layer or scattered crystals (Choi
 657 et al., 2018; Packard & DeMarco, 1991; Stewart et al., 2010).

658 There are differing accounts on the microstructure of monotreme eggshells, however
 659 conceptus coats include three layers including zona pellucida, mocooid coat and shell coat
 660 (Frankenberg & Renfree, 2018). Further studies are needed test for secondary homology.
 661 Monotreme shells are described as proteinaceous, permeable, and flexible (Hughes, 1984).
 662 Marsupials lack an eggshell but have an eggshell coat, similar to that of monotremes
 663 (Frankenberg & Renfree, 2018), that is secreted by the epithelial cells and endometrial glands
 664 early on in embryonic development prior to implantation (Roberts et al., 1994; Roberts & Breed,
 665 1996). Upon hatching of the shell coat and attachment of the embryo, a cooperative
 666 inflammatory response ensues (Stadtmauer et al., 2020a, 2020b).

667 **Table 1.** Amniote Eggshell Ultrastructures

Taxon	Eggshell ultrastructure
Testudoid	Radial aragonite with organic core at base
Crocodiloid	Tabular, arranged in wedges of calcite with no organic core
Squamate	Two types: <ul style="list-style-type: none"> • rigid-shelled eggs with well-developed crystalline layer (dibamid and gekkonid lizards). Stem-like crystals grow downward making for a rigid shell • flexible-shelled eggs with parchment-like shell of fibrils overlaid with little thin crystal caps or no crystalline material (other squamates)
Ornithoid (avian)	Calcite with a clear boundary between lower and upper parts. Mammillary layer defines the lower portion of the shell, with calcite crystals that radiate upwards
Monotreme	Distensible, permeable and highly proteinaceous

668 Note: Adapted from Choi et al., (2018); Frankenberg & Renfree, (2018); Hallman & Griebeler, (2015); Hincke et
669 al., (2012); Trauth & Fagerberg, (1984)

670

671

672 (2) *Uterine glands & the evolution of parity modes*

673 Eggshell formation occurs in the uterus where the uterine glands secrete precursors of the
674 eggshell (Girling, 2002; Guillette, Fox & Palmer, 1989; Jonchère et al., 2010; Nys et al., 2004;
675 Picariello et al., 1989; Stewart & Ecaj, 2010). Uterine glands are critical for gravidity/gestation
676 in both oviparous and viviparous amniotes (Braz et al., 2018; Burton et al., 2002; Cooke et al.,
677 2013). For example, in humans, uterine glands provide histiotrophic nutrition to the early
678 embryo (Burton et al., 2002). In reptiles, precursors for the proteinaceous eggshell membrane are
679 secreted by the uterine glands (Corso, Delitala & Carcupino, 2000; Heulin et al., 2005; Palmer et
680 al., 1993). Calcium secretion can also involve uterine epithelial cells (Herbert, Thompson &
681 Lindsay, 2006; Thompson et al., 2007). Uterine epithelium of the soft-shelled turtle, *Lissemys*
682 *punctata punctata*, and the eastern collard skink, *Chrotaphytus collaris* stain positive for calcium
683 (Guillette et al., 1989; Sarkar et al., 1995).

684 Viviparous squamates have an absent or reduced eggshell membrane to facilitate gas
685 exchange (Blackburn, 1993; Braz et al., 2018) Some squamates are encased in the thin
686 membrane through the entirety of development like the viviparous lizard, *Zootoca vivipara*
687 (Heulin, 1989). Others have the membrane only in the early stages of embryonic development
688 like in garter snakes *Thamnophis radix* and *T. sirtalis* (Blackburn & Lorenz, 2003). Calcium
689 deposits are detected on the outer surface of the membrane throughout development in other
690 viviparous lizards (Stewart et al., 2013).

691 Reduced number or size of eggshell glands leads to reduced eggshell membrane thickness in
692 viviparous squamates. In chickens, variation in size, spacing, and neutron density of eggshell
693 glands may also be important for eggshell structure (Guillette & Jones, 1985). In the

694 reproductively bimodal Yellow-bellied three toed skink, *Saiphos equalis*, the density of eggshell
695 glands plays a role in eggshell thickness (Stewart et al., 2010). In the reproductively bimodal
696 lizard, *Zootoca vivipara*, viviparous individuals have a uterine glandular layer that is less
697 developed during the stage of eggshell formation compared to oviparous individuals (Heulin et
698 al., 2005). Additionally, in *Lerista fragilis*, which lays eggs that hatch within just hours of
699 oviposition, the uterus contains very few mucosal glands (Guillette, 1992). In the fence lizard,
700 *Sceloporus a. aeneus*, the irregular surface of the eggshell was attributed to the irregular spacing
701 of shell glands (Guillette & Jones, 1985). In an oviparous gecko, *Hemidactylus turcicus*, their
702 eggshell glands have loosely packed secretory granules that produce a hard, calcareous shell
703 (Girling et al., 1998). In a comparison of oviparous and viviparous water snakes from the genus
704 *Helicops*, viviparous embryos have thinner shell membranes which associated with reduced size
705 of eggshell glands (Braz et al., 2018). In an oviparous gecko, *Saltuarius wyberba*, their secretory
706 granules are tightly packed, and their shell is soft and parchmentlike (Girling et al., 1998). In a
707 viviparous relative, *Hoplodactylus maculatus*, there are far fewer eggshell glands, and where
708 there are glands, the secretory granules are smaller and more electron dense (Girling, Cree &
709 Guillette, 1997; Girling, Cree & Guillette, 1998). Smaller eggshell gland size during or after
710 vitellogenesis is also found in other viviparous squamates compared to oviparous counterparts
711 (Braz et al., 2018; Gao et al., 2019; Heulin et al., 2005). To my knowledge, in monotremes the
712 relationship between eggshell thickness and shell gland size, density or compaction of secretory
713 granules has not been explored.

714 In the oviparous Przewalski's toadhead agama lizard, *Phrynocephalus przewalskii*, 148 genes
715 are highly expressed in the uterus during the stage of eggshell gland development (Gao et al.,
716 2019). Only three of these are highly expressed in *P. vlangalii*, a viviparous close relative at this

717 time, suggesting differences in oviparous and viviparous eggshell gland development requires
718 regulatory changes to dozens of genes (Gao et al., 2019). In the opossum, a marsupial,
719 proliferation of uterine glands is not induced by the conceptus (Griffith et al., 2019).

720

721 (3) *Evolutionary implications of the physiology of eggshell formation*

722 Presumably because of the influence it has on food production, the process of eggshell
723 formation has been studied most extensively in chickens (Hincke et al., 2012). The avian
724 eggshell is formed in a cell-free environment, and it is the fastest calcifying process known to
725 biology (Hincke et al., 2012; Rodríguez-Navarro et al., 2015). During eggshell formation in
726 birds, uterine fluid containing a supersaturation of ionized calcium and bicarbonate ions
727 surrounds the egg (Nys et al., 1991). Transport of calcium in the uterus correlates with plasma
728 membrane Ca^{2+} -ATPase (*PMCA*) activity and with concentrations of calbindin-D28K within
729 shell gland epithelial cells (Herbert et al., 2006; Wasserman et al., 1991). This leads to the
730 spontaneous precipitation of calcium carbonate into calcite (Hincke et al., 2012). In the
731 oviparous lizard, *Lampropholis guichenoti*, immunofluorescence microscopy revealed activity of
732 *PMCA* in the uterus at the time of eggshell calcification (Thompson et al., 2007).

733 Eggshell formation begins with the eggshell membrane. Two unciliated cell types in the
734 uterus contribute to eggshell membrane formation in a viviparous skink, *Chalcides ocellatus*
735 *tiligugu* (Corso et al., 2000). One secretes sulfated glycosaminoglycans to form the inner shell
736 membrane, and the other which secretes acidic glycoproteins to form the outer layers (Corso et
737 al., 2000). Simple alveolar glands in the lamina propria secrete collagen fibers (Corso et al.,
738 2000). Inhibition of fiber formation or cross-linking, typically caused by aminopropionitrile or a

739 copper deficiency, causes distorted formations of the eggshell membrane in birds (Arias et al.,
740 1997; Chowdhury & Davis, 1995; Hincke et al., 2012).

741 In characteristic Archelosaur eggshells (Choi et al., 2018; Legendre et al., 2022), organic
742 aggregates are deposited onto the shell membrane creating mammillary knobs, which are absent
743 in Lepidosaur shells (Choi et al., 2018). Mammillary knobs are a distinct layer between the outer
744 eggshell membrane and the calcified shell matrix layer (Hamilton, 1986). Part of the mammillary
745 knobs, called basal caps, are embedded into the outer eggshell membrane fibers (Tyler, 1965).
746 Mammillary knobs serve as regions of crystal initiation where ACC is deposited (Gautron et al.,
747 2021) and converted into calcite crystals with no intermediate phase (Rodríguez-Navarro et al.,
748 2015). Cones are formed that radiate in all upward directions, extending up to the shell matrix
749 layer (Tyler, 1965). Despite the direct relationship between mammillary knobs and calcium
750 carbonate crystallization (Rao et al., 2015), the protein comprising mammillary knobs remains
751 uncharacterized. A keratan sulfate (KS)-proteoglycan, “mammillan”, has been implicated in the
752 composition of mammillary knobs (Fernandez et al., 2001; Hincke et al., 2012). Any given
753 proteoglycan is a product of multiple coding genes and biosynthesis of KS-proteoglycans is non-
754 trivial (Caterson & Melrose, 2018; Funderburgh, 2002; Iozzo et al., 2015). However,
755 investigations into the keratan sulfate proteoglycan proposed as “mammillan” and identifying its
756 Properties that Facilitate Calcium Deposition (P-FCD) has far reaching implications given that
757 KS-proteoglycans are proving to be important players in neurological and cancer research
758 (Leiphrakpam et al., 2019). The role of homologs of “mammillan” in eggshell formation in
759 squamates may reveal more about the evolutionary history of the eggshell in amniotes.

760 Parsimony would suggest that all oviparous amniotes shared an ancestral process of
761 eggshell formation. In Archelosaurs, the process of eggshell formation relies on mammillary

762 knobs and upward growth of calcite, as described above. In Lepidosaur eggshells, which have
763 substantially less calcite growth, calcium is deposited on the surface of the eggshell membrane
764 and, in the case of gekkonids and the tuatara, crystal growth proceeds inward toward the center
765 (Choi et al., 2018). The strikingly divergent structure and directionality of eggshell formation
766 between Archelosauria and Lepidosauria suggests that the dissimilar processes of eggshell
767 formation are a result of genetic drift (e.g. Schiffman & Ralph, 2022), selection for specific
768 eggshell traits, or, in the case of an early origin of viviparity in Amniotes (Jiang et al., 2023)
769 and/or Lepidosauria (Pyron & Burbrink, 2014), eggshells are a derived convergent trait.

770 Hypothetically, if a version of the avian eggshell was the microstructure for basal
771 Lepidosauria, loss of mammillary knobs and their basal caps should have prevented calcium
772 deposition since mammillary knobs are the site at which calcium carbonate spontaneously
773 precipitates into calcite in Archelosaurs. Given that embryonic signaling supports at least two
774 main differences between oviparous and viviparous squamates—the timing of calcium secretions
775 and the length of embryonic retention (Griffith et al., 2015, 2017; Stewart & Ecy, 2010)—the
776 loss of mammillary knobs/basal caps may have supported an early origin of viviparity in
777 squamates. It would have theoretically facilitated 1) an early loss of the eggshell, 2) enhanced
778 contact between maternal and embryonic tissues and 3) enhanced signaling from the embryo to
779 support both altered timing of calcium secretions and hormonal signaling for extended
780 embryonic retention. This potential mechanism for an early origin of viviparity in squamates is
781 proposed here, for the first time, as the basal cap hypothesis. When mammillary knobs originated
782 is of paramount importance to the basal cap hypothesis, and inferences that can be gained from
783 applying it to the evolution of oviparity and viviparity in amniotes. If a version of the avian
784 eggshell was the ancestral microstructure of oviparous amniotes, the loss of basal caps could

785 result in a rapid loss of the eggshell and thus a relatively fast transition to viviparity or extended
786 embryonic retention.

787 Extending to the ancestral state of amniotes (e.g. Jiang et al., 2023; Laurin, 2005; Romero,
788 1957), absence of functional “mammillan” with P-FCD in squamates and mammals would be
789 consistent with a derived state of calcified eggshells in Archelosaurs. Absence of functional
790 “mammillan” with P-FCD exclusively in Lepidosaurians would be consistent with the basal cap
791 hypothesis. Presence of functional “mammillan” with P-FCD across Amniota would be
792 consistent with the conventional understanding that the amniote egg evolved to prevent
793 desiccation and enable gas exchange following oviposition of eggs on land (Romero, 1957).
794 Overall, identifying the evolutionary trajectories of the biosynthetic pathway of “mammillan”
795 across amniotes is likely to create a better picture of the evolution of the amniote egg.

796 New recommendations for estimating ancestral microstructure of amniote eggshells have
797 recently been put forth, which abandons the traditional classification of hard/soft/semi-rigid
798 shells (Legendre et al., 2022). Including the structure of eggshell membranes in viviparous
799 squamates (e.g. Corso et al., 2000) would also improve phylogenetic reconstructions of the
800 amniote eggshell.

801 Several pieces of biological evidence lend themselves to an early origin of viviparity in
802 Lepidosaurians and the basal cap hypothesis including—the lack of homology between the semi-
803 rigid shells of testudines and Lepidosaurians (Legendre et al., 2022), the later stage of embryonic
804 development when eggs are commonly oviposited in squamates (Blackburn, 1995), and the more
805 predominant reliance on yolk calcium rather than eggshell calcium in squamates compared to
806 Archelosaurs (Packard, 1994; Stewart & Ecyar 2010). Viviparity in the most recent common
807 ancestor of Lepidosaurians may provide clear evolutionary insights on these phenomena.

808 Other features of eggshells are also worth consideration. In chickens, ovotransferrin is
809 present in the eggshell membrane and basal cap-layer (Gautron, Hincke, Panhéleux et al., 2001).
810 Ovotransferrin promotes the development of elongated crystals (Gautron, Hincke, Panhéleux et
811 al., 2001). The resulting shell matrix is made up of the crystal layer and cuticle (Hamilton, 1986).
812 On the inner portion of the avian eggshell, it is unclear what prevents growing crystalized cones
813 from extending into the inner membrane or the albumen. Collagen type X has been implicated
814 (Arias et al., 1993, 1997; Hincke et al., 2012). The role of collagen type X in creating a boundary
815 that prevents calcite from passing through the eggshell membrane could inform squamate
816 eggshells deposition (as discussed, they deposit calcium only on the outer surface, or crystals
817 grow inward). The only non-avian eggshell matrix protein, pelovaterin, was identified in the soft-
818 shell turtle (Lakshminarayanan et al., 2005).

819 Over 500 proteins are found in the chicken eggshell matrix (Mann, Maček, & Olsen, 2006;
820 Mikšík et al., 2007, 2010). Ovocleidin-116 (*OC-116*), ovocalyxin-36 (*OCX-36* or *BPIFB4*),
821 ovocalyxin-21 (*OCX-21*), and ovocleidin-17 (*OC-17*) are important for avian eggshell formation
822 (Hernández-Hernández, Gomez-Morales et al., 2008; Jonchère et al., 2010; Tian et al., 2010).
823 *OC-116*, *OC-36*, *OCX-21*, and *OC-17* are some of the most differentially expressed genes during
824 eggshell calcification in chickens (Gautron et al., 2007; Hincke et al., 1999, 2012; Jonchère et al.,
825 2010). Ovocalyxin-21 may serve as a chaperone protein along with the protein endoplasmic
826 (ENPL) to facilitate proper folding of the avian eggshell matrix (Jonchère et al., 2010). In birds,
827 *OC-17* is concentrated in the inner mammillary cone layer, it interacts strongly with ACC, and it
828 is implicated in early stages of biomineralization of the eggshell (Gautron et al., 2021).

829 Originally considered avian-specific, several homologs of avian eggshell matrix proteins
830 have now been identified in non-avian reptiles and mammals (Le Roy et al., 2021). A recent

831 study found a significantly reduced number of intact avian eggshell matrix proteins in viviparous
832 squamates compared to oviparous squamates, a pattern that was especially apparent in snakes
833 (Xie et al., 2022). This study also found that *OC-17* was only absent in viviparous squamates but
834 was always present in the oviparous species in the dataset (Xie et al., 2022). Due to this, and the
835 central role of *OC-17* in avian eggshell formation in birds, they ascribe losing intact *OC17* with
836 the prevention of reversals back to oviparity (Xie et al., 2022). However, given that *OC-17* is
837 implicated in initiation of mineralization in the mammillary cone layer, which is absent in
838 squamates, the necessity of *OC-17* for squamates eggshell formation requires further
839 investigation. Other genes, like osteopontin (*OPN* or *SPPI*), also play a central role in
840 biomineralization of the avian eggshell and should be investigated in squamates.

841 *OCX-36* and other bactericidal/permeability-increasing (BPI) family B proteins (also called
842 *LPLUNCs*) are now thought to have a common origin in vertebrates with multiple duplication
843 events (Gautron et al., 2007; Tian et al., 2010). Orthologs of *OCX-36* are found in Archelosauria
844 and Monotremata (Le Roy et al., 2021). In birds, *OCX-36* plays a role in innate immune
845 responses and is found in high concentrations in the inner eggshell membrane (Gautron et al.,
846 2007, 2011; Tian et al., 2010).

847 *OC-116* is homologous to mammalian *MEPE*, which plays a role in bone and teeth
848 mineralization (Bardet et al., 2010a, 2010b). In birds, *OC-116* influences shell thickness, elastic
849 modulus, and egg shape (Le Roy et al., 2021). *OC-116* was identified in a crocodile, *Crocodylus*
850 *siamensis*, proteome (Le Roy et al., 2021; Mikšík et al., 2018). Synteny analysis across seven
851 turtle species and platypus (*Ornithorhynchus anatinus*) revealed absence of *MEPE/OC116* (Le
852 Roy et al., 2021). Other genes and lncRNAs are purported to be important for the quality of
853 eggshell formation in hens—*FGF14*, *COL25A1*, *GPX8*, and several members of the solute

854 carrier protein (*SLC*) gene family (Yang et al., 2020). Research into lncRNAs activity in
855 squamate reproductive tissues during embryonic development represents another valuable track
856 for research.

857 Various evolutionary genomics studies have revealed squamate-specific candidates for shell
858 formation (e.g. Recknagel et al., 2021a; Gao et al., 2020). Some of these candidates span the
859 major clades of amniotes. Seven of the genes expressed during eggshell gland development in
860 *Phrynocephalus przewalskii*—*HYPOUI*, *KCNMA1*, *P4HB*, *PRDX4*, *PTN*, *RRBP1* and
861 *TRAMI*—are purported to be important for eggshell calcification in chickens (Brionne et al.,
862 2014). Given this overlap across species that diverged over 300 million years ago (Shen et al.,
863 2011), these are excellent candidates for further exploration.

864 A functional genomics study harnessed hybridizations of oviparous and viviparous
865 individuals of *Zootoca vivipara* to reveal 17 SNPs and 38 genes associated with eggshell traits
866 (Recknagel et al., 2021a). These genes enriched terms related to cell communication and the
867 immune system, while differentially expressed gene during gravidity enriched pathways for
868 transforming growth factor (Recknagel et al., 2021a). The three loci with the strongest
869 association with eggshell traits mapped closely to *LG MN*, *LYPLA1*, and *CRTCI* (Recknagel et
870 al., 2021a). The association of these genes with eggshell traits is particularly interesting. *LG MN*,
871 for example, is involved with the cadherin pathway. Cadherins have an established role in
872 squamate reproduction. In squamates, previous literature discusses how cadherins influence
873 embryonic attachment in viviparous taxa (Wu et al., 2011). *LG MN* is also differentially
874 expressed across many viviparous squamates and mammals (Recknagel et al., 2021a). Thus,
875 *LG MN*, appears to support both oviparous and viviparous gestation in different ways. There are a
876 number of ways to approach exploring how *LG MN* may support both maternal-fetal

877 interconnectivity (viviparous individuals) and eggshell formation (oviparous individuals). Cell-
878 to-cell communication analysis using single cell data on uteruses of a reproductively bimodal
879 species would enable researchers to identify different interaction networks of *LGMN* and
880 associated cells in oviparous vs viviparous individuals.

881 During gravidity in *Saiphos equalis* two GO terms associated with calcium homeostasis are
882 enriched by the set of upregulated genes (Foster et al., 2020). However, most of these genes are
883 associated with regular cellular responses to calcium and even those associated with calcium
884 transport are upregulated in both early and late stages of gravidity (Foster et al., 2020). Their role
885 in eggshell formation in this uniquely labile species is therefore ambiguous.

886 In oviparous individuals of another reproductively bimodal skink, *Lerista bougainvillii*, only
887 two genes are significantly differentially expressed in the gravid uterine tissue compared to non-
888 gravid uterine tissue (Griffith et al., 2016). No genes are differentially expressed in the gravid
889 uterine tissue of the oviparous garden skink, *Lampropholis guichenoti*, compared to non-gravid
890 uterine tissue (Griffith et al., 2016). The genes involved in the shelling process in these species
891 may not involve changes in expression from the non-gravid state. The dissimilarity in uterine
892 gene expression profiles across lizards during gravidity suggests there may be multiple ways
893 oviparous squamates shell their eggs. Given the variation already observed, the eggshell
894 deposition in squamates should be considered in a phylogenetic context and under the different
895 evolutionary history inferred by ancestral state reconstructions (Harrington & Reeder, 2017;
896 Pyron & Burbrink, 2014). Supplementary table 1 compares candidate genes associated with
897 eggshell formation and shell gland development in squamates to that of birds.

898

899 (4) *Pleiotropy of genes and proteins involved with eggshell formation*

900 Substantial pleiotropy of genes involved with eggshell formation would imply that regardless
901 of parity mode, taxa have innately conserved toolkits that can be readily exploited to form an
902 eggshell for oviparous gestation. In addition to the candidate genes associated with both
903 gestation length and eggshell traits in *Zootoca vivipara* (Reckagel et al., 2021a), several genes
904 associated with eggshell deposition have pleiotropic effects within species or have different
905 effects in oviparous vs. viviparous amniotes. Osteopontin (*SPP1* or *OPN*) is found in bone and
906 kidneys, and transports calcium to other tissues in the body (Pines et al., 1995). It plays an
907 important role in calcium carbonate biomineralization of the avian eggshell (Gautron et al.,
908 2021). It is highly expressed in the chicken uterus during calcification (Jonchère et al., 2010) but
909 supports pregnancy recognition and implantation in sheep (Bazer et al., 2011). Improper
910 functioning of *SPP1* in the uterus leads to cracked and abnormal shells in birds (Arazi et al.,
911 2009; Hincke et al., 2008).

912 When expressed in the uterus, some bone morphogenic protein-coding genes (*BMPs*) aid
913 eggshell calcification (Jonchère et al., 2010). *BMPs* are part of the *TGF- β* superfamily and are
914 involved with the formation of new cartilage and bone, and with biomineralization in corals and
915 mollusks (Canalis et al., 2003; Lelong et al., 2000; Zoccola et al., 2009). Chordin (*CHRD*) is an
916 antagonist of the *BMP* pathway. *BMP*-binding endothelial regulatory protein (*BMPER*) and
917 *CHRD* are expressed in the chicken uterus during the stage of eggshell calcification (Jonchère et
918 al. 2010). Regulation of *BMPs* by *CHRD* is essential for early embryogenesis and adult
919 homoeostasis.

920 *BMPER* and seven *BMPs* are expressed during gestation in *Chalcides ocellatus*, a viviparous
921 skink (Brandley et al., 2012). Most of these are upregulated (Brandley et al. 2012). *BMP* genes
922 are expressed during both gravidity and non-gravidity in oviparous *Lerista bougainvillii* and

923 *Lampropholis guichenoti* (Griffith et al., 2016). *BMP2* is upregulated in oviparous late gestation
924 compared to viviparous late gestation in the reproductively bimodal lizard, *Saiphos equalis*
925 (Foster et al., 2020).

926 Differential expression of *BMPR1B* is associated with differences in eggshell quality in
927 chickens (Yang et al., 2020). Another study associated stage-specific high-expression of
928 *BMPR1B* with the stage corresponding to extended embryonic retention and placentation in
929 *Phrynocephalus vlangalii* (Gao et al., 2019). They identified a co-expression network of highly
930 expressed genes, including *BMPR1B*, that they associated with placentation (Gao et al., 2019).
931 *BMPR1B* also reaches significant levels of differential expression in uterine tissues of other
932 gestating viviparous lizards, *Chalcides ocellatus* and *Pseudemoia entrecasteauxii*, compared to
933 non-gestational uterine tissue (Brandley et al., 2012; Griffith et al., 2016). Receptors for *BMPs*
934 are also expressed in the uterus during gestation in other viviparous lizards, *Phrynocephalus*
935 *vlangalii* and *Pseudemoia entrecasteauxii* (Gao et al., 2019; Griffith et al., 2016). Perhaps
936 unsurprisingly, *BMPR1B* is also differentially expressed in the uterus of viviparous *Zootoca*
937 *vivipara* compared to oviparous individuals during gestation.

938 The potential role of these genes in squamate eggshell formation remains unclear. *BMPs*
939 influence on dorsal-ventral axis patterning during early embryogenesis and growth of skeletal
940 structures in post-natal tissues (Medeiros & Crump, 2012). It may be difficult to disentangle their
941 roles in embryonic development, placental development, and eggshell deposition. Future
942 research on them may inform scientific understanding of parity mode evolution.

943 *SLIT* genes are purported to be involved with folding the eggshell matrix in chickens
944 (Jonchère et al., 2010). The *SLIT2* gene functions across birds and mammals in diverse organs,
945 and encodes a protein that provides a structural framework for protein-protein interactions

946 (Jonchère et al., 2010; Marillat et al., 2002). In a functional genomics study, *SLIT2* was
947 identified as an important gene for eggshell traits in *Zootoca vivipara* (Recknagel et al., 2021a).
948 *SLIT2* is among the 50 most downregulated genes in the uterus during pregnancy in the
949 viviparous African ocellated skink, *Chalcides ocellatus*, compared to non-pregnancy (Brandley
950 et al., 2012). However, in the uterus of the yolk-sac placenta in the viviparous skink, *Pseudemoia*
951 *entrecasteauxii*, *SLIT2* is upregulated compared to non-reproductive uterine tissue (Griffith et al.,
952 2016). *SLIT3* is differentially expressed during the stage of placentation in the viviparous agama
953 lizard, *Phrynocephalus vlangalii* (Gao et al., 2019). *SLIT* genes also play a role in axonal
954 pathfinding and neuronal migration in rats (Marillat et al., 2002). *SLIT2* was associated with
955 reproduction in humans (Chen, Chu et al., 2015).

956 Podocalyxin (*PODXL*) is a sialoprotein associated with eggshell calcification in chickens
957 (Jonchère et al., 2010). In the viviparous Qinghai toad-headed agama lizard, *Phrynocephalus*
958 *vlangalii*, a weighted gene correlation network analysis associated *PODXL* with uterine
959 structural changes (Gao et al., 2019). The gene may play a role in placentation in these species
960 given that it was also differentially expressed in the uterus during the stage of placentation (Gao
961 et al., 2019). Interestingly, *PODXL* is downregulated in the uterus of the yolk-sac placenta in
962 another viviparous skink, *Pseudemoia entrecasteauxii* (Griffith et al., 2016). Based on its role in
963 chickens and *P. vlangalii*, *PODXL* is a good candidate for further research on the molecular
964 evolution of eggshell formation and placentation in squamates.

965

966 (5) Eggshell formation termination

967 When eggshell formation is terminated, the egg is still bathed in the supersaturated
968 calcium and bicarbonate ion fluid (Hincke et al., 2012). Some component(s) of the terminal

969 uterine fluid may prevent precipitation of calcium carbonate (Gautron, Hincke & Nys, 1997),
970 such as phosphate anions (Lin & Singer, 2005). The presence of phosphorous in the superficial
971 layers of the chicken shell suggest it may be a factor preventing the deposition of calcite crystals
972 in the terminal stage. Additionally, the high concentration of *OCX-32* in the outer eggshell and
973 cuticle, suggest that the gene may inhibit proteinaceous crystal growth in the terminal stage of
974 eggshell calcification (Gautron, Hincke, Mann et al., 2001). It is informative to viviparous
975 reproduction and consistent with the basal cap hypothesis that exposure to precursors of the
976 eggshell does not necessitate eggshell deposition. The influence of phosphate anions and *OCX-*
977 *32* on inhibition of calcium carbonate precipitation on the eggshell membrane of viviparous
978 squamate embryos has not been examined to my knowledge.

979

980 *(6) Rotating the egg for eggshell formation*

981 Oviparous amniotes rotate the egg for calcium formation and viviparous mammals rotate the
982 embryos for parturition. One hurdle to reversing back to oviparity may be re-evolving rotation of
983 the egg for shell formation early in gravidity (Griffith et al., 2015). Given the complex
984 musculature of the uterus across taxa, that allows for multidirectional force for parturition and
985 eggshell formation, it is difficult to determine the degree of difficulty for re-evolving appropriate
986 timing of egg-rotation. Cadherins and hormonal signaling support embryonic attachment (Wu et
987 al., 2011; Biazik et al., 2012), which can prevent rotation of the egg. Oviparous taxa lack
988 embryonic attachment, enabling the uterus to rotate the egg for eggshell formation. This rotation
989 does not happen until later in gestation for eutherian mammals when, for example, the embryo
990 detaches and cadherins become less concentrated (Wu et al., 2011). Perhaps a candidate gene for
991 studying this is, a cadherin *CDH5*, the only gene that is differentially expressed in all viviparous

992 squamates studied thus far studied (Recknagel et al., 2021a). Genes that enrich the GO term for
993 “voltage-gated calcium channel activity” are also useful candidates for investigating uterine
994 rotation associated with eggshell formation because voltage-gated calcium channels effect the
995 action potential of cells and can cause muscle contractions.

996

997 (7) Discussion & future directions—eggshell formation and parity mode evolution

998 The process of eggshell formation is more resolved in birds compared to non-avian reptiles
999 and monotremes (Choi et al., 2018; Frankenberg & Renfree 2018). I described some overlaps
1000 gleaned from the literature which prove as curious candidates for further research
1001 (Supplementary Table 1). Of particular interest are avian eggshell matrix proteins (Alföldi et al.,
1002 2011; Le Roy et al., 2021; Tian et al., 2010; Xie et al., 2022), genes with biomineralizations
1003 functions, candidate genes associated with eggshell traits in *Zootoca vivipara* (Recknagel et al.,
1004 2021a), and the homologs for avian eggshell matrix proteins identified in the *Anolis carolinensis*
1005 genome (Alföldi et al., 2011; Tian et al., 2010). Additionally, genes purported to be important for
1006 eggshell calcification in chickens associated with eggshell gland formation in an oviparous
1007 lizard, *Phrynocephalus przewalskii*, are relevant—*HYPOUI*, *KCNMA1*, *P4HB*, *PRDX4*, *PTN*,
1008 *RRBPI* and *TRAMI* (Brionne et al., 2014; Gao et al., 2019). Overlaps between the genes
1009 associated with gestation length and eggshell traits in *Zootoca vivipara* (Recknagel et al., 2021a)
1010 hint at genes that could potentially evolve to innately effect multiple traits relevant to parity
1011 mode transitions. The basal cap hypothesis also offers a simple evolutionary mechanism to
1012 investigate the evolutionary history of amniote parity mode evolution (see section III.3).
1013 Alternatives to the basal cap hypothesis are that dissimilar eggshells and eggshell deposition

1014 processes evolved through selective pressure, genetic drift, or both. Fortunately, the basal cap
1015 hypothesis can be utilized to ascertain the likelihood of this.

1016

1017 **IV. Placentation & Transport of Embryonic Water, Gas, and Nutrients**

1018

1019 The evolutionary pressures on fluid allocation, gas exchange and nutrient transport should
1020 differ between oviparous and viviparous taxa because their sources of all or some of these
1021 resources differ (Blackburn, 1992; Bonnet et al., 2001; Bonnet, Naulleau & Shine, 2017; van
1022 Dyke et al., 2014). In viviparity, maternal gas and water are accessed through the chorioallantois,
1023 which is especially important in the latter half of development (van Dyke et al., 2014; Carter,
1024 2012). Nutrients can be available from the yolk, maternal transfer, or both yolk and maternal
1025 transfer.

1026 While viviparity is associated with shared patterns of uterine gene expression during amniote
1027 gestation (Recknagel et al., 2021a), the same does not occur in viviparous amniote placentas
1028 (Foster et al., 2022). Instead, different genes that serve similar functions are recruited to the
1029 placenta across independent origins of viviparity (Foster et al., 2022). Additionally, where other
1030 amniotes can rely on the albumen for fluid allocation, squamates lack an albumen (Blackburn &
1031 Stewart, 2021). The eggshells of various squamates supports uptake of water from the
1032 environment (Blackburn & Stewart, 2021). The evolutionary implications of this have not been
1033 documented to my knowledge.

1034

1035 *(1) Anatomy & methods of water, gas & nutrient provisioning*

1036 The embryonic membranes regulate embryonic fluid transport, nutrient supply, respiration,
1037 immunity, and waste (Brace, 1997; Burton & Tullett, 1985; Ferner & Mess, 2011; Packard &
1038 Packard, 1980). Fluids are important for the developing embryo because they prevent desiccation
1039 and compression (Ferner & Mess, 2011; Packard & Packard, 1980). Over-abundance or under
1040 abundance of embryonic sac fluids leads to reproductive failure (Chamberlain et al., 1984;
1041 Fedakâr et al., 2016; Hadi, Hodson & Strickland, 1994; Mercer et al., 1984). Water is the
1042 predominant resource provisioned from the mother in most viviparous squamates (Lourdais et
1043 al., 2015).

1044 Oxygen flux in embryonic mammals is largely determined by oxygen-diffusing capacity of
1045 the placenta, the rates of blood flow in the umbilical and uterine arteries, and the oxygen
1046 capacities and affinities of fetal and maternal blood (Carter, 2009). Reptilian and mammalian
1047 blood vessels differ in basic characteristics such as capillary density, capillary surface, and
1048 oxygen diffusion gradients (Pough, 1980). Oviparous taxa regulate gas exchange through pores
1049 in their eggshells.

1050 Patterns of embryonic nutrient exchange can be broadly categorized into lecithotrophy,
1051 obtaining nutrients from the yolk, and placentrophy or matrotrophy, obtaining nutrients from the
1052 mother. Taxa belonging to Archelosauridae are lecithotrophic. The ancestral state of mammals
1053 was most likely oviparous matrotrophy that later evolved into viviparous matrotrophy in therians
1054 (Blackburn, 2005). The ancestral state of reptiles was likely lecithotrophy (Blackburn, 2005).
1055 Most viviparous squamates are lecithotrophic, some are lecithotrophic and matrotrophic, and a
1056 few have specializations for substantial matrotrophy (e.g. Blackburn, 2015a, Blackburn, 1985b;
1057 Stewart & Thompson, 1993; Thompson, Stewart et al., 1999; van Dyke et al., 2014). Even in
1058 lecithotrophic viviparous squamates some degree of organic or inorganic nutrients pass through

1059 the chorioallantoic placenta (Blackburn, 2005; Swain & Jones, 1997, 2000; Stewart & Eday,
1060 2010; Thompson, Stewart et al., 1999; Thompson & Speake, 2002). Reversals may be most
1061 unlikely in lineages that have specialized placentas for substantial nutrient exchange because
1062 they would need to re-evolve lecithotrophy. Highly matrotrophic squamates are extremely rare
1063 (Blackburn, 2015a).

1064

1065 *(2) Evolutionary history of yolk-sac formation and yolk processing*

1066 Vitellogenesis is the process of yolk formation in the oocyte, providing the embryo with a
1067 valuable source of nutrients, primarily through the accumulation of precursor proteins to yolk,
1068 vitellogenins. Vitellogenin is produced in the liver, called hepatic vitellogenesis, and transported
1069 to the maturing ovum (Ho, 1987). Vitellogenins were lost in all mammals except monotremes
1070 (Brawand, Wahli & Kaessmann, 2008). They are a primary source of nutrition for other
1071 amniotes. Functionally similar to vitellogenin, caseins have persisted in all mammalian milks
1072 (Brawand et al., 2008). Active functioning of the yolk sac is restricted to the first trimester in
1073 placental mammals, and it is postulated to provide nutrients to the embryo (Kuzima et al., 2023).
1074 The detection of glycodelin in the yolk sac epithelium also supports this (Burton et al., 2002). In
1075 the yolk-sac of bats, dogs, and non-human primates the mesoderm derived layer is absorptive
1076 and may transfer substances from the exocoelomic cavity where the yolk sac is located (Enders
1077 et al., 1976; Freyer & Renfree, 2009; King & Wilson, 1983; Lee et al., 1983).

1078 The morphology of the yolk-sac and process of vitellogenesis differs between birds and non-
1079 avian reptiles. In birds, during the process of meroblastic cleavage, the zygote's cells divide
1080 while the yolk component does not. The yolk forms a large, fluid, non-cellularized mass
1081 surrounded by the extraembryonic yolk sac. The formation of the yolk-sac placenta in birds has

1082 the following pattern—first the bilaminar omphalopleure forms and then trilaminar
1083 omphalopleure; blood vessels move into folds of the extraembryonic endoderm, becoming
1084 stratified epithelium; the folds carrying the blood vessels reach the peripheral regions of the yolk
1085 only and the center of the yolk mass remains uncellularized (Starck, 2021). Intensive
1086 development of hemopoietic tissue surrounding the blood vessels during most of embryonic
1087 development, thus far, appears to be unique to birds (Starck, 2021). Compared to non-avian
1088 sauropsids, the unique pattern of yolk processing in birds facilitates faster embryonic
1089 development (Blackburn, 2021).

1090 The yolk sac characteristic of non-avian reptilian eggs serves as a model for the transition
1091 between the egg of anamniotes and amniotes (Blackburn, 2020). A series of recent papers,
1092 covering species of snakes, lizards, crocodiles, and turtles, indicate that these taxa utilize similar
1093 developmental pathways of yolk-sac formation and yolk processing that differs from birds
1094 (Blackburn, 2020, 2021; Blackburn et al., 2019; Elinson et al., 2014; Elinson & Stewart 2014;
1095 Stinnett et al., 2011). Across these taxa, a bilaminar/trilaminar omphalopleure overgrows the
1096 yolk mass, and the yolk mass gets invaded by proliferating endodermal cells that phagocytose
1097 the yolk material. These cells form clumps, progressively filling the yolk mass. Small blood
1098 vessels derived from yolk sac vasculature invade the yolk sac cavity and the endodermal cells
1099 arrange in monolayers around these vessels, forming “spaghetti bands” (Blackburn, 2021). The
1100 yolk sac of *Pantherophis guttatus* is one suitable model for studying the transition of the yolk-
1101 sac from anamniotes to amniotes (Elinson & Stewart, 2014; Elinson et al., 2014).

1102 A major difference between non-avian reptilian yolk-sac formation is the morphology and
1103 extent of vascularization and cellularization in the yolk sac cavity (Starck, 2021). Birds have a
1104 yolk-sac with absorptive endodermal lining that digests nutrients and send them into blood

1105 circulation (Starck, 2021) whereas snakes, lizards, turtles, and crocodylians have a yolk sac that
1106 becomes invaded by endodermal cells that proliferate and phagocytose yolk material (Blackburn,
1107 2021). In these taxa, yolk material becomes cellularized, digested, and transported by vitelline
1108 vessels to the developing embryo (Blackburn, 2021). Factors involved with cellularization of the
1109 yolk-sac are proposed to include cell cycle regulators and structural proteins (Elinson et al.,
1110 2014). Generation of these cells are suspected to be reliant on processes of angiogenesis and are
1111 likely transcriptionally active (Elinson et al., 2014). Few transcriptomic profiles of yolk-sac
1112 placentas in reptiles have been documented to my knowledge (Griffith et al., 2016). Significant
1113 overlaps in the yolk-sac transcriptomes of human, mice, and chicken—including apolipoproteins
1114 and SLC transporters—however, suggest functional conservation (Cindrova-Davies et al., 2017).

1115 As discussed in a previous section, progesterone inhibits myometrial contractility, but it also
1116 inhibits estrogen-induced hepatic vitellogenin synthesis (Custodia-Lora, Novillo, & Callard,
1117 2004; Callard et al., 1992). Variable progesterone concentrations in circulation throughout
1118 gestation in viviparous squamates may reflect a trade-off to allow estrogen expression to support
1119 hepatic vitellogenin synthesis during embryonic development, thus supporting nutrient
1120 provisioning during the lengthened embryonic retention. Although hepatic vitellogenesis usually
1121 ceases during gestation, vitellogenin synthesis and mother-to-embryo transfer was detected in
1122 one viviparous fish, *Xenotoca eiseni*, during gestation (Iida et al., 2019). Future research should
1123 consider the timing of vitellogenin synthesis throughout the reproductive cycle in gestating and
1124 non-gestating viviparous squamates to investigate this further.

1125

1126 (3) *Evolutionary history of placentrophy in mammals & squamates*

1127 Traditionally, it was thought that placentrophy evolved after viviparity in squamates
1128 (Packard, Tracy, & Roth, 1977; Shine & Bull, 1979). Further research demonstrated that
1129 placentrophy and viviparity evolved simultaneously (incipient matrotrophy) in mammals and
1130 may have in squamates (Blackburn, 1985, 1992, 2005, 2006; Stewart & Eday, 2010). The
1131 incipient matrotrophy model relies on evidence that 1) uterine provisioning of nutrients predates
1132 the origin of viviparity (Blackburn 1985, 1992, 2006), 2) uterine and embryonic tissues have a
1133 close anatomical and physiological association in viviparous taxa and 3) some degree of
1134 placental transfer of organic or inorganic molecules occurs in viviparous taxa (Stewart & Eday,
1135 2010). In squamates, the potential for both incipient matrotrophy and evolution of placentrophy
1136 after viviparity is supported (Stewart & Eday, 2010). Facultative placental nutrient provisioning
1137 and incipient matrotrophy may have driven the evolution of squamates with substantial
1138 matrotrophic nutrient provisioning (Stewart, 2020; Swain & Jones, 2000).

1139 Placentation and implantation are not homologous in mammals compared to squamates
1140 (Griffith, van Dyke & Thompson, 2013). Several placental specializations for gas and nutrient
1141 exchange are unique to mammals including erosion of the uterine mucosa, extensively invasive
1142 implantation, hemochorial contact, retention of a vascularized choriovitelline membrane, and
1143 countercurrent patterns of blood flow (Blackburn, 2005). This enables extensive exchange of
1144 nutrients in addition to water and gas. The vast majority of viviparous squamates have the most
1145 superficial type of chorioallantoic placenta called epitheliochorial placenta (Blackburn, 1993).

1146 Nutrient provisioning through placentrophy is obligate for embryonic development in only
1147 five lineages of squamates, all of which are scincid lizards (Blackburn, 2000; Flemming &
1148 Blackburn, 2003; Ramírez-Pinilla et al., 2011; van Dyke et al., 2014). *Pseudemoia*
1149 *pagenstecheri*, a lizard with a highly specialized placenta, out-performs lecithotrophic oviparous

1150 close relatives in the relative amount of nutrients it transfers to the embryo (Stewart et al., 2009).
1151 *Pseudemoia entrecasteauxii* is a moderately matrotrophic viviparous skink, with roughly half of
1152 embryonic nutrient uptake from the yolk and half through a specialized cyto-epitheliochorial
1153 placenta (Adams et al., 2005; Speake et al., 2004; Stewart & Thompson, 1993, 2009).

1154 Specializations of the chorioallantoic placenta for nutrient provisioning in some squamates
1155 include elaborate specializations for uterine secretion and absorption, including placentomes,
1156 chorionic areolae, hypertrophied uterine mucosa, and chorionic epithelia modified for absorption
1157 (Blackburn, 2005). In squamates, specializations for gas exchange across the chorioallantoic
1158 placenta include decreased diffusion distance between maternal and fetal capillaries, uterine
1159 vascularity, shell membrane deterioration, and modifications of both fetal and maternal blood
1160 properties (Blackburn, 1998, 2005; Blackburn & Lorenz, 2003; Blackburn & Vitt, 2002).

1161 Mammalian placenta-specific genes have deep origins in vertebrates (Rawn & Cross, 2008).
1162 Placentation to support viviparity likely employs genes that are ancestral to the chorioallantois.
1163 However, one study that looked at placentation and gene expression across a small sample of
1164 divergent amniotes found only one gene with a placentrophy-specific pattern of gene expression,
1165 *DIO3* (Griffith, Brandley et al., 2017). In mammals, *DIO3* is an imprinted gene and
1166 preferentially paternally expressed. The authors suggest that the gene may increase offspring
1167 resource uptake during pregnancy in the horse and a viviparous lizard, *Pseudemoia*
1168 *entrecasteauxii*, where it is recruited to the placenta (Griffith, Brandley et al., 2017).

1169

1170 (4) Genes involved with embryonic water, gas, and nutrient transport

1171 Water transport in animals is regulated by a family of molecular water channels called
1172 aquaporins (AQs or AQPs) (Borgnia et al., 1999). In humans, *AQP1*, *AQP3*, *AQP4*, *AQP8* and

1173 *AQP9* are found in the placenta but further research is needed to understand how these influence
1174 water fluxes between maternal and fetal tissues (Damiano, 2011). Transcriptomic analysis on
1175 uterine tissue of the gestating, viviparous skink, *Chalcides ocellatus*, reveal differential
1176 expression of *AQP1*, *AQP3*, *AQP5*, *AQP6*, *AQP8*, *AQP9* and *AQP11* when compared to non-
1177 gestating uteruses (Brandley et al., 2012). In birds, *AQP1* is expressed in the chorioallantoic
1178 membrane, and it is suggested to influence angiogenesis throughout embryonic development
1179 (Ribatti et al., 2002). In a viviparous lizard, *Pseudemoia entrecasteauxii*, *AQP8* and *AQP9* were
1180 more highly expressed in the chorioallantoic placenta compared to the yolk-sac placenta (Griffith
1181 et al., 2016). During gestation in both oviparous and viviparous populations of the reproductively
1182 bimodal skink, *Saiphos equalis*, several genes involved with water homeostasis are upregulated
1183 in the uterus including *AQP1*, *AQP3* and *AQP12B* (Foster et al., 2020). In uteruses of *Saiphos*
1184 *equalis*, *AQP5* and *AQP8* are upregulated during oviparous late gestation compared to viviparous
1185 late gestation. In sheep, *AQP3* is differentially expressed during gestation, where it serves a dual
1186 role of water transport to the embryo and fetal urea export (Johnston et al., 2000). This is similar
1187 to the function of *AQP9* in humans (Damiano, 2011). Immunocytochemistry reveals that *AQP1*
1188 and *AQP3* are expressed in the uterus of the highly placentrophic South American scincid lizard,
1189 *Mabuya sp.* (Wooding et al., 2010). In *Zootoca vivipara*, *AQP9* is upregulated at midgestation
1190 (Recknagel et al., 2021a).

1191 Some molecules are implicated in the regulation of aquaporins including insulin (INS),
1192 human chorionic gonadotropin (HcG), cyclic adenosine monophosphate (cAMP) and cystic
1193 fibrosis transmembrane conductance regulator (CFTR) (Damiano, 2011). Genes predicted to be
1194 involved with reproduction in *Anolis carolinensis* are enriched for the GO term for cAMP-
1195 mediated signaling (Alföldi, Di Palma, et al., 2011). Further comparative research should be

1196 done to elucidate the functional differences of aquaporins in oviparous and viviparous amniotes
1197 and how they relate to the differing conditions under which these embryos develop.

1198 Genes involved embryonic oxygen transport precede the origin of amniotes. Hemoproteins
1199 arose in evolutionary history well before they were used for placental oxygen transfer (Hardison
1200 1998). In mammals, adult (Alpha: HBA; Beta: HBB, HBD) and embryonic hemoglobins (Alpha:
1201 HBZ, HBA; Beta: HBE, HBG, and HBH) are involved with oxygen transport (Carter, 2012).
1202 Some of these are unique to eutherian mammals following a series of duplication events (Opazo
1203 et al., 2008). However, fetal hemoglobins are found in turtles, lizards, and snakes (Pough, 1980).
1204 HBA, HBB and HBM are all significantly downregulated in the uterine tissue of the viviparous
1205 African Ocellated Skink, *Chalcides ocellatus*, during gestation compared to non-gestation
1206 (Brandley et al., 2012). The oxygen demands of reptile embryos are relatively low until stage 30,
1207 when most oviparous taxa oviposit (Shine & Thompson, 2006). In viviparous and oviparous
1208 species with long egg retention, embryonic demand for maternal provision of oxygen and
1209 removal of CO₂ increases at this stage.

1210 Improper water, gas and nutrient exchange can occur due to poor chorioallantoic blood flow
1211 (Wootton et al., 1977). Thus, viviparous taxa require greater degrees of vascularization and
1212 vasodilation to facilitate enhanced requirements for maternal resources compared to oviparous
1213 taxa. Rather than increasing the size of the placenta, increasingly dense blood vessels can support
1214 fetal growth without compromising space for embryonic growth as occurs in some pigs (Ford,
1215 1997; Vonnahme et al., 2002). Embryonic vascularization and vasodilation are dependent on
1216 signals from the endoderm (Jin et al., 2005; Vokes & Krieg, 2002; Wilt, 1965). In oviparous
1217 individuals of *Saiphos equalis*, populations with extended egg retention, there is expansion of the
1218 uterine vascular bed and thickening of the chorioallantoic tissue that supports increased

1219 embryonic growth in the later portion of oviparous gravidity (Parker et al., 2010). In the
1220 viviparous scincid lizard, *Eulamprus quoyii*, angiogenesis, the formation of new blood vessels,
1221 and expansion of the vessel-dense elliptical area of the uterus is associated with supporting
1222 increased embryonic oxygen demand (Murphy et al., 2010).

1223 Several protein-coding genes are known to be involved with angiogenesis, vascularization,
1224 and vasodilation in utero. One study that examined expression patterns across chickens
1225 (oviparous), horses (viviparous), two viviparous squamates, and one oviparous squamate found
1226 that no examined genes for angiogenesis showed a viviparity-specific expression pattern
1227 (Griffith, Brandley et al., 2017). However, other than the chicken, the only oviparous taxa
1228 included in this study was a reproductively bimodal skink, *Lerista bougainvillii* (Griffith,
1229 Brandley et al., 2017). Alternatively, differential gene expression analyses on oviparous and
1230 viviparous individuals of *Zootoca vivipara*, revealed pathways for angiogenesis enriched in
1231 viviparous female reproductive tissues; and pathways for angiogenesis were enriched across
1232 genes under divergent selection in oviparous and viviparous *Z. vivipara* individuals.

1233 In the uterine tissue of gestating viviparous skinks and rats, several genes for angiogenesis
1234 are upregulated—*EPASI*, *HIF1A* and *VEGFA* (Brandley et al., 2012; Whittington et al., 2015,
1235 2017). Other proteins involved in vascularization and vasodilation in utero include members of
1236 the vascular endothelial growth factor (*VEGF*) gene family, VEGF receptors (*VEGFRs*),
1237 placental growth factor (*PGF*) and nitric oxide synthase (*NOS*) (Blomberg et al., 2010; Chen,
1238 Wang et al., 2015; Gilbert, 2010; Reynolds et al., 2006; Risau, 1997; Torry et al., 2003;
1239 Vonnahme et al., 2001). In *Saiphos equalis*, different homologs of *NOS* experience different
1240 patterns of gene expression across the oviparous and viviparous stages of gestation/gravidity
1241 (Foster et al., 2020). One homolog of *NOS* is upregulated during oviparous late gestation, and

1242 another is upregulated during viviparous late gestation (Foster et al., 2020). Several genes
1243 involved with angiogenesis and vascular morphogenesis are downregulated in the pre-
1244 implantation uterus of a marsupial, the Fat Tailed Dunnart, *Sminthopsis crassicaudata*—
1245 *ADGRA2, ADGRB2, ANGPTL1, EPHB4, ISM1, PDZRN3, RHOJ, TNMD,* and *VEGFD*
1246 (Whittington et al., 2018).

1247 In humans, immune factors are also responsible for increasing embryonic blood supply.
1248 Embryonic non-classical MHC class I molecule, HLA-G, and uterine natural killer (uNK) cells
1249 support increased embryonic blood supply (Moffett & Loke, 2006; Rajagopalan et al., 2006). A
1250 similar pattern of utilizing immune properties to support embryonic blood supply has not been
1251 yet identified in squamates.

1252 Lipids are a main energy source for embryos. Lipoprotein lipase (LPL) is an important
1253 enzyme in lipid transport. LPL is significantly expressed on the syncytiotrophoblasts, specialized
1254 placental cells, of humans (Lindegaard et al., 2005) and the endometrium of cows (Forde et al.,
1255 2011), and pigs (Ramsay et al., 1991), where it plays a role in lipid mobilization. A viviparous
1256 lizard, *Pseudemoia entrecasteauxii*, increases capacity for lipid transport toward the end of
1257 pregnancy (Griffith, van Dyke & Thompson, 2013). The uterine tissue of the yolk-sac placenta in
1258 this species had significantly higher expression of LPL than the uterine tissues of the
1259 chorioallantoic placenta (Griffith, van Dyke & Thompson, 2013), leading the authors to suggest
1260 that the yolk-sac placenta is the major site of lipid transport. LPL expression was not detected
1261 during pregnancy in the viviparous skink, *Chalcides ocellatus* (Blackburn, 1992; Brandley et al.,
1262 2012). Instead, lipid transport may be facilitated by fatty acid binding proteins in this species
1263 (Chmurzyńska, 2006; Brandley et al., 2012). These are also active on mammalian placenta
1264 (Haggarty, 2002).

1265 Apolipoproteins are also suitable candidates for transport of fatty acids, cholesterol, and
1266 phospholipids. Five of these (*APOA1*, *APOA2*, *APOA4*, *APOE*, and *APOM*) and *APOA1BP* are
1267 significantly upregulated in the pregnant uterus of the viviparous skink, *Chalcides ocellatus*
1268 (Brandley et al., 2012). *APOA1BP* is also upregulated in the uterus of the chorioallantoic
1269 placenta and yolk-sac placenta compared to non-gestational uterine tissues in *Pseudemoia*
1270 *entrecaeauxii* (Griffith et al., 2016). Additionally, upregulation of 136 genes that encode solute
1271 carrier proteins (SLCs) in the pregnant uterus of *Chalcides ocellatus* are associated with
1272 transport of inorganic ions, metals, glucose, amino acids, peptides, fatty acids, and carboxylic
1273 acids (Brandley et al., 2012).

1274 Supply of amino acids is required for embryonic development. SLCs have important
1275 transport functions, including the transport of amino acids, and thus they are considered to be
1276 important for gestation (Foster et al., 2022). However, a recent study found no overlap in the
1277 amino acid transporting SLCs upregulated in placentas of viviparous placentrophic vertebrates
1278 studied, which included eight representatives from Mammalia, Reptilia, and Chondrichthyes
1279 (Foster et al., 2022). However, *SLC38A3* was upregulated in all viviparous species except *Rattus*
1280 *norvegicus* (Foster et al., 2022).

1281 Cathepsins and phospholipases are important for uterine secretions for embryonic
1282 development in horses, pigs, sheep, and cattle (Bazer, 1975; Satterfield et al., 2007; Song et al.,
1283 2010). Cathepsins are present in yolk sacs of humans and mice. They function to degrade
1284 proteins to free amino acids (Cindrova-Davies et al., 2017). Two genes for cathepsin L (*CTSL1*
1285 and *CTSL2*) are upregulated in the uterus during gestation in *Chalcides ocellatus* (Brandley et al.,
1286 2012). *CTSL* is also upregulated in the uterus during the pre-implantation phase in the Fat-Tailed
1287 Dunnart, *Sminthopsis crassicaudata* (Whittington et al., 2018), and in the uterus of the

1288 chorioallantoic placenta and uterus of the yolk sac placenta during gestation in *Pseudemoia*
1289 *entrecasteauxii* (Griffith et al., 2016).

1290 In viviparous individuals of the reproductively bimodal lizard, *Saiphos equalis*, many genes
1291 for cellular adhesion are upregulated during late gestation (Foster et al., 2020). The authors
1292 postulated that this helps facilitate maternal-fetal signaling and paracellular transport (Foster et
1293 al., 2020). Gao et al. (2019) identified a set of genes in *Phrynocephalus vlangalii* that were
1294 differentially expressed in the uterus during the stage of placentation and these enriched GO
1295 terms functionally related to the process of placentation. This included an estrogen receptor
1296 (*ESRI*) and two growth factor receptors (*GHR* and *IGFIR*) (Gao et al., 2019).

1297 Finally, the proteomes of the ovary and placenta from obligately placentrophic *Mabuya*
1298 lizards can further serve as a useful resource for examining nutrient provisioning in squamates
1299 (Hernández-Díaz et al., 2017). In the placenta they found protein expression involved with
1300 nutrient metabolism, transport, protein synthesis, and embryonic development (Hernández-Díaz
1301 et al., 2017).

1302

1303 (5) Uterine glands: adenogenesis, placenta development and histotrophy

1304 In addition to their role in eggshell deposition in oviparous taxa, uterine glands also secrete
1305 growth factors and cytokines that support placental development in mammals. In humans, these
1306 include transforming growth factor- β (TGF- β), epidermal growth factor (EGF), vascular
1307 endothelial growth factor (VECG), and leukemia inhibitory factor (LIF) (Hempstock et al.,
1308 2004). In eutherians, TGF- β supports placental development by regulating proliferation and
1309 invasion rates of placental cells lines (Caniggia et al., 2000; Hempstock et al., 2004; Lafontaine
1310 et al., 2011).

1311 Histotrophy (also called histiotrophy) occurs when nutrients are secreted into the uterine
1312 lumen from vesicles of the columnar epithelial cells of the uterus and taken up by the embryo.
1313 Histotrophic nutrient provisioning is documented across amniotes including marsupials
1314 (Whittington et al., 2018), several ungulate taxa (Bazer et al., 2011; Han et al., 2016; Gao et al.,
1315 2009), humans (Burton et al., 2002), and appear to occur in some viviparous squamates (van
1316 Dyke et al., 2014). In humans, histotrophic nutrient provisioning occurs during the first trimester.
1317 The intervillous space is filled with fluid containing uterine gland secretions that get
1318 phagocytosed by the syncytiotrophoblasts and are the initial nutrient source for the fetus (Burton
1319 et al., 2002). Two of these glycoproteins are epithelial mucin (*MUC1*) and glycodefin A (*GdA*)
1320 (Burton et al., 2002). Interestingly, the *MUC15* gene is upregulated during gravidity/gestation in
1321 the uterus of oviparous and viviparous *Saiphos equalis* individuals (Foster et al., 2020). This also
1322 occurs in the chorioallantoic placenta of *Pseudemoia entrecasteauxii* during gestation (Griffith et
1323 al., 2016). Several mucins are expressed in the uterus in non-gravid and gravid samples from
1324 oviparous individuals of *Lerista bougainvillii* and *Lampropholis guichenoti* (Griffith et al.,
1325 2016).

1326 A survey of viviparous squamates with modest to extensive placentrophy revealed
1327 prevalence of histotrophic nutrient provisioning rather than hemotrophy, transfer of nutrients
1328 between maternal and fetal blood streams (Blackburn 2015). Embryos of *Chalcides chalcides*
1329 have extensive placentrophy that supports substantial maternal nutrient provisioning and
1330 histotrophy (Blackburn, 2015a). Histotrophy may lessen parent-offspring conflict and give the
1331 mother the control over nutrient provisioning compared to hemotrophy (Blackburn, 2015b).

1332 *Chalcides ocellatus* has less extensive placentrophy than *C. chalcides* but the gestating uterus
1333 still illustrates expression of many genes associated with organic and inorganic nutrient transport

1334 (Blackburn, 2015a). Multiple *TGF-β* genes are differentially expressed in the uterus during
1335 gestation in *C. ocellatus*, however most these are downregulated compared to non-gestational
1336 uterine tissue (Murphy et al., 2012). The influence of *TGF-β* on placental development and
1337 nutrient provisioning in *Chalcides spp.* remains to be explored to my knowledge. A TGF-β
1338 receptor (*TGFBRI*) was associated with placental development in *Phrynocephalus vlangalii*
1339 (Gao et al., 2019).

1340 Essential to histotrophy is adenogenesis, the generation of endometrial glands. Adenogenesis
1341 allows for the secretion of histotrophs. The period of early development during which
1342 adenogenesis occurs is highly variable among vertebrates but it is required for embryonic
1343 survival (Gray et al., 2001, 2002; Spencer & Bazer, 2004). Some genes involved with
1344 adenogenesis in sheep are insulin-like growth factor 1 (*IGF-1*), *IGF-2*, *PAX2*, *LHX1* (also known
1345 as *LIM1*) and *EMX2*, genes in the abdominal-B HOXA cluster, members of both *Wnt* and
1346 Hedgehog (*Hh*) gene families (Fazleabas et al., 2004), prolactin (*PRL*), fibroblast growth factor 7
1347 (*FGF7*), *FGF10*, *FGFR2IIIb*, hepatocyte growth factor (*HGF*), a receptor tyrosine kinase (*c-*
1348 *Met*), and cadherins (Fazleabas, 2007).

1349 In the gestating uterus of *Chalcides ocellatus*, insulin-like growth factor-binding protein 5
1350 (*IGFBP5*) is one of the most significantly downregulated genes compared to non-gestational
1351 uterine tissue (Brandley et al., 2012). *IGFBP5* is evolutionarily conserved and multifunctional,
1352 with an important role in regulating IGF signaling, including that of *IGF-1* and *IGF-2* (Duan &
1353 Allard, 2020). Other than adenogenesis in sheep, IGFs serve an important role in the growth of
1354 fetal and maternal tissues in mammals (Gibson et al., 2001; Kampmann et al., 2019).

1355 Genes involved with histotrophic secretion in the marsupial *Sminthopsis crassicaudata*
1356 include *AP4SI*, *HYOU1*, and *SRPRA* (Whittington et al., 2018). Nutrient transporters

1357 significantly upregulated at this time are *APOL6* (cholesterol transport (Baardman et al., 2013)),
1358 *PLA2G10* (hydrolysis of fatty acids during pregnancy (Miele et al., 1987)) and a wealth of SLCs
1359 (solute carrier proteins for transport of sugar, ions, anions, glucose, fatty acids, calcium and zinc
1360 (Whittington et al., 2018)). Subsequent research has identified downregulated of *HYOUI* at early
1361 and mid-gestation; and downregulation of *SRPRA* at mid-gestation in viviparous *Zootoca*
1362 *vivipara* compared to oviparous (Recknagel et al., 2021a). In a reproductively bimodal skink,
1363 *Saiphos equalis*, *PLA2G10* is upregulated during viviparous late gestation compared to oviparous
1364 late gestation (Foster et al., 2020). Upregulation of SLCs also occurs in the viviparous skink
1365 *Chalcides ocellatus* (Brandley et al., 2012; Van Dyke et al., 2014) and in the uterus during
1366 pregnancy in the grey short-tailed opossum, *Monodelphis domestica* (Hansen, Schilkey & Miller,
1367 2016).

1368 Uterine glands are also important for secretions of eggshell precursors. I speculate that genes
1369 involved with adenogenesis of uterine glands may be similarly used to support histotrophic
1370 nutrient provisioning during transitions to viviparity, but further research is necessary.

1371 Specialized uterine areolar glands are found in some *Mabuya* lizards, a genus with oviparous
1372 species and viviparous species that utilize placentrophy and histotrophy (Corso et al., 1988,
1373 2000; Jerez & Ramírez-Pinilla, 2001; Ramírez-Pinilla, 2006; Vieira et al., 2007; Visser, 1975).

1374 Transcriptomic research focused on histotrophic nutrient provisioning, placental development,
1375 and secretions of eggshell precursors in oviparous and viviparous *Mabuya spp.* would
1376 complement literature on the genus.

1377

1378 (6) *Discussion & future directions—embryonic nutrients, gas, and water supply*

1379 Many genes for placental functions in mammals have deep origins in vertebrates (Rawn &
1380 Cross, 2008). In pairwise comparisons of different viviparous amniotes, there is overlap in
1381 hormones and proteins (SLC superfamily, insulin-like growth factors, aquaporins and solute
1382 carrier proteins, etc.) involved in uterine remodeling, placentation, and placental transport. While
1383 shared genes are recruited to the uterus across viviparous amniotes (Recknagel et al 2021a), there
1384 are no shared genes recruited to the placenta across viviparous reptiles, mammals, and sharks
1385 (Foster et al., 2022). Evolutionarily, this suggests higher conservation of the regulatory networks
1386 associated with uterine responses to viviparity than placental responses to viviparity. The
1387 relationship of these findings to embryonic nutrient provisioning and the evolution of the
1388 amniotic egg requires further investigation. Supplementary Table 2 illustrates how genes
1389 mentioned in text for water, gas, and nutrient transport are expressed in reproductive tissues of
1390 squamates during gestation and gravidity.

1391 If specific genes or physiological processes impact more than one of the Main Five
1392 categories, it could have a disproportionate influence on transitions. Such an overlap has already
1393 been identified in *Zootoca vivipara*, where 11 genes are associated with both eggshell traits and
1394 gestation length (Recknagel et al., 2021a). The solute carrier (*SLC*) gene superfamily is involved
1395 with both nutrient transport (Brandley et al., 2012; Whittington et al., 2018) and eggshell
1396 deposition (Yang et al., 2020). Adenogenesis is essential for histotrophic nutrient provisioning
1397 and secretion of eggshell precursors. Additionally, progesterone production influences both
1398 uterine quiescence, which is an important state to maintain in lengthened embryonic retention,
1399 and it also inhibits hepatic vitellogenesis, an important process for lecithotrophic nutrient
1400 provisioning. Thus, examining the role of *SLC* gene superfamily members, processes of

1401 adenogenesis, and progesterone production during embryonic development in oviparous and
1402 viviparous squamate may reveal how interconnectivity of the Main Five are.

1403

1404 **V. Embryonic Calcium Provisioning**

1405

1406 The embryonic growth stage requires the greatest demand of calcium (Ecay et al., 2017;
1407 Packard & Packard, 1984; Stewart & Ecay, 2010). To support this, peak uterine concentrations
1408 of calcium are highest during either eggshell deposition or during the embryonic growth stage, in
1409 oviparous and viviparous taxa, respectively (Linville et al., 2010; Stewart et al., 2009).
1410 Regardless of parity mode, embryonic metabolism drives calcium uptake (Packard & Packard,
1411 1984). The calcium source(s) utilized have clade-specific implications on the genomic and/or
1412 physiological changes required to transition between parity modes.

1413

1414 *(1) Phylogenetic context of embryonic calcium sources*

1415 Calcium can be acquired by the embryo in three forms: calcium carbonate in the eggshell,
1416 calcium bound to proteins and lipids in the yolk, and/or free ionic calcium from maternal
1417 delivery through the placenta (Stewart & Ecay, 2010). These correspond with five calcium
1418 mobilization patterns: 1) Birds, turtles and crocodiles predominately depend on the eggshell; 2)
1419 Most squamates, regardless of parity mode, predominately depend on the yolk; 3) Some
1420 squamate species are reliant on both the eggshell and yolk; 4) Some viviparous squamate species
1421 are reliant on both the yolk and placenta; and 5) therian mammals and rare viviparous squamates
1422 predominately depend on the placenta (Blackburn, 2015a; Hoenderop, Nilius, & Bindels, 2005;
1423 Jenkins & Simkiss, 1968; Kovacs, 2015; Packard, 1994; Packard & Seymour, 1997; Stewart et

1424 al., 2009, 2009; Stewart & Ecy, 2010; Thompson, Stewart et al., 1999; Thompson, Stewart, &
1425 Speake, 2000; Ramírez-Pinilla, 2006).

1426 From an evolutionary perspective, squamate eggs might serve as the best models of the
1427 ancestral amniote egg. Unlike birds, oviparous squamates generally rely on yolk calcium rather
1428 than eggshell calcium. The yolk sac of non-avian reptiles is a good model for the transition
1429 between the egg of anamniotes and amniotes (Blackburn, 2020). Taken together and given that
1430 hard calcified eggshells of Archelosaurs are likely derived (as discussed in section III.3)—
1431 squamate eggs may have the closest resemblance to the ancestral amniote egg. Interestingly, to
1432 my knowledge, oviparous squamates do not sequester calcium from the eggshell into the yolk
1433 during incubation (Packard, 1994).

1434

1435 *(2) Hypotheses on calcium mobilization and the evolution of parity modes*

1436 It was hypothesized that predominant reliance on eggshell calcium should constrain lineages
1437 to oviparity because the evolution of viviparity would result in a lost calcium source (hereafter
1438 eggshell calcium constraint hypothesis) (Stewart & Ecy, 2010; Packard et al., 1977; Packard &
1439 Packard, 1984). This hypothesis suggested that viviparity should only evolve in lineages
1440 predominately reliant on yolk calcium (Packard et al., 1977; Packard & Packard, 1984).

1441 Fittingly, birds, turtles and crocodilians generally rely on eggshell calcium, and they are
1442 constrained to oviparity (Anderson et al., 1987). The eggshell calcium constraint hypothesis
1443 holds true for most viviparous squamates that rely heavily on yolk calcium (Stewart & Castillo,
1444 1984; Stewart & Ecy, 2010; van Dyke et al., 2014).

1445 Subsequent research revealed that viviparity is not constrained by a prerequisite reliance on
1446 yolk calcium. Oviparous scincid skinks studied thus far are intermediately reliant on eggshell and

1447 yolk calcium (Linville et al., 2010; Shadrix et al., 1994; Stewart et al., 2009; Stewart &
1448 Thompson, 1993; Thompson et al., 2001). Calcium placentrophy contributes substantially to
1449 embryonic development in several viviparous squamates including *Pseudemoia entrecasteauxii*,
1450 *Eulamprus quoyi*, *Zootoca vivipara*, *Saiphos equalis*, and a species of *Mabuya* lizard (Ecay et al.,
1451 2017; Linville et al., 2010; Ramírez-Pinilla, 2006; Ramírez-Pinilla et al., 2011; Stewart &
1452 Thompson, 1993). These taxa, with the exception of *Zootoca vivipara*, are in the family
1453 Scincidae (Burbrink et al., 2020), which is also the family with the most independent origins of
1454 viviparity in squamates (Blackburn, 1982, 1999; Pyron & Burbrink, 2014).

1455 To understand the breadth of physiological conditions from which oviparity and viviparity
1456 evolve in squamates, future research should examine calcium transport in other lineages. Studies
1457 focused on snakes would be particularly informative given the sparse literature on them.

1458 *Helicops angulatus*, a reproductively bimodal water snake from South America, is an ideal
1459 model for this (Braz et al., 2016). Thus far, many oviparous snakes are known to be
1460 intermediately reliant on yolk and eggshell calcium. This has not precluded viviparity from
1461 evolving in these lineages.

1462 The presence of embryos during extended embryonic retention may trigger positive feedback
1463 stimuli for continued uterine calcium secretions which may support placental calcium transport,
1464 and thus incipient calcium matrotrophy (Stewart & Ecay, 2010). This is postulated to resemble
1465 the hormonal and mechanical stress mechanisms implicated in avian eggshell formation and
1466 uterine calcium secretions (Bar, 2009a; Stewart & Ecay, 2010). The influx of calcium late in
1467 viviparous gestation may be triggered in part by embryonic growth that over distends the uterus.
1468 This is seen in studies on myometrial stretch in mammals when uterine overdistention triggers
1469 spikes in calcium (Kao & McCullough, 1975; and see e.g. Wray et al., 2015).

1470 Dramatic changes to activity in chorioallantois should not be required during parity mode
1471 transitions because these homologous tissues (Metcalf & Stock, 1993) transport calcium
1472 regardless of parity mode (Ecay, Stewart & Blackburn, 2004; Tuan & Scott, 1977; Tuan &
1473 Knowles, 1984; Tuan et al., 1978, 1986). Specialized placental structures in some viviparous
1474 squamates enhance calcium provisioning but specialization is not required for placental calcium
1475 transport (Stewart et al., 2009; Stewart & Ecay, 2010; Thompson et al., 2000). Loss of
1476 chorioallantoic calcium transporting capacity would be disadvantageous to either parity mode.
1477 Growing research reveals that, like mammals, placentrophy and viviparity can evolve
1478 concurrently in squamates (Blackburn, 2015a; Ecay et al., 2017; Stewart & Ecay, 2010).

1479 Placing these previously proposed models in a phylogenetic context, the calcium transport
1480 method of oviparous ancestors likely has an influence on the method of calcium transport used
1481 for viviparous taxa—matrotrophic calcium provisioning, lecithotrophic calcium provisioning, or
1482 a combination of the two. Consistent with the basal cap hypothesis—when viviparity arises from
1483 oviparous ancestors with embryos that depended predominately on eggshell calcium, this should
1484 favor a transition to viviparity via incipient calcium matrotrophy because the chorioallantois
1485 already plays the major role in transporting calcium from the eggshell to the embryo. Since the
1486 reproductive mode and calcium provisioning of oviparous ancestors are essentially unknown,
1487 researchers can use the closest oviparous relatives as proxies. Similarly, viviparous taxa that are
1488 in close phylogenetic proximity to oviparous taxa that depend on lecithotrophic calcium
1489 provisioning should remain reliant on yolk calcium. Together, these guidelines provide a
1490 framework from which researchers can form hypotheses about the calcium provisioning method
1491 of a viviparous lineage if the calcium provisioning method of oviparous close relatives are
1492 known, or vice versa. Measurements of the proportional contribution of different calcium sources

1493 during development has only been done in select taxa (e.g. Packard, 1994; Stewart, 2013;
1494 Stewart & Ecy, 2010; Stewart, Ecy & Blackburn 2004). Once validated, the framework (i.e.,
1495 the calcium provisioning method of close relatives) can help increase the speed at which science
1496 measures and infers the evolutionary history of calcium provisioning across amniotes and
1497 squamates. Collection of this data across the squamate phylogeny may enable assignment of
1498 these hypotheses to specific clades.

1499 Embryonic calcium source could have implications on the physiological changes required to
1500 transition between parity modes. Reliance on yolk calcium should render, essentially, no
1501 mechanistic changes for calcium transport. On the other hand, incipient calcium matrotrophy
1502 requires regulatory changes in the uterus, like timing of calcium secretions (Griffith et al., 2015).
1503 However, regardless of parity mode 1) the uterus secretes calcium, 2) the chorioallantois
1504 transports calcium and 3) embryonic metabolism drives uptake of calcium. Assuming maternal
1505 tissue remains responsive to embryonic metabolism, the joint evolution of matrotrophic calcium
1506 provisioning with viviparity may require little to no physiological adjustments.

1507 The diversity of embryonic calcium provisioning patterns in viviparous squamates may not
1508 be fully explained by the eggshell calcium constraint hypothesis (Packard et al., 1977; Packard &
1509 Packard, 1984) or incipient calcium matrotrophy (Stewart & Ecy, 2010). Both hypotheses
1510 implicitly assume that viviparity equates to a lost eggshell. In one viviparous squamate, *Haldea*
1511 *striatula*, and in viviparous populations of two reproductively bimodal lizards, *Zootoca vivipara*
1512 and *Saiphos equalis*, the calcified eggshell is considered as a component of the placenta (Stewart,
1513 2013). Some other viviparous squamates have transient calcified patches on their embryonic
1514 membranes (Blackburn, 1998; Heulin, 1990, 2005; Qualls, 1996) suggesting that uterine calcium
1515 secreting capabilities in early gestation may be retained in some viviparous lineages. In the case

1516 of reversals, it remains unknown how the uterus shifts back to early calcium secretions after
1517 ovulation (Blackburn, 2015b; Griffith et al., 2015).

1518

1519 *(3) Embryonic calcium provisioning mechanisms*

1520 In vertebrates, specialized tissues that recover environmental calcium and transport it into
1521 blood circulation maintain conserved mechanisms for intracellular calcium transport (Bronner
1522 2003; Hoenderop et al., 2005). These include the uterus, chorioallantoic tissues, and yolk
1523 splanchnopleure (Bronner, 2003; Hoenderop et al., 2005; Stewart, 2013). Therefore, uterine and
1524 embryonic tissues may be pre-adapted for maternal and embryonic calcium provisioning.

1525 In birds, a sub-compartment of the mammillary layer of the eggshell is the calcium reserve
1526 body (Chien et al., 2009), which contains microcrystals of calcite that get dissolved and
1527 transported as calcium to the embryo (Chien et al., 2009). Calcium is eroded from the eggshell
1528 by acid released from villus cavity cells (VCCs) in chorioallantoic membrane (Anderson, Gay,
1529 and Schraer, 1981; Narbaitz et al., 1981; Packard & Lohmiller, 2002; Simkiss, 1980). This
1530 increases the carbonic anhydrase activity of the cells enabling calcium to be released into the
1531 cavity between the eggshell and the chorionic epithelium, where it is taken up by capillary
1532 covering cells (CCCs) in chorioallantoic membrane (Coleman & Terepka, 1972). In some
1533 species this erosion leads to a gradual weakening of the eggshell that facilitates hatching (Chien,
1534 Hincke & McKee, 2008). In chickens, transcalcin, a calcium binding protein, is credited for the
1535 calcium transporting capacity of the chorioallantoic membrane (Tuan & Knowles, 1984; Tuan &
1536 Ono, 1986; Tuan & Scott, 1977; Tuan et al., 1978, 1986). The presence of VCCs and CCCs in
1537 the chorioallantois of viviparous squamates would indicate a known route through which calcium
1538 can be absorbed.

1539 Transcellular calcium transport has been modeled as a three-step process involving proteins
1540 calbindin-D9K, calbindin-D28K, and the highly calcium-specific ion channels of the transient
1541 receptor potential vanilloid gene family (*TRPV5* and *TRPV6*) (Stewart & Ecaj, 2010). Across
1542 vertebrates, this machinery is shared in epithelial tissues with significant roles in calcium
1543 transport (Hoenderop et al., 2005). Estrogen and vitamin D3 have regulatory roles in this
1544 process.

1545 Calbindin-D9K, calbindin-D28K, *TRPV5*, and *TRPV6* is involved with calcium exchange in
1546 multiple organs of birds, squamates, and mammals. Broadly, activity of calbindin-D9K and/or
1547 calbindin-D28K is associated with patterns of calcium absorption in the mammalian kidney and
1548 uterus (Bindels, 1993; Luu et al., 2004), murine uterus and placenta (Lafond & Simoneau, 2006;
1549 Koo et al., 2012), and chicken duodenum and uterus (Bar, 2009b; Yang et al., 2013). In humans,
1550 calbindin-D9K and calbindin-D28K are critical to the active transport of Ca²⁺ across placental
1551 cells (Faulk & McIntyre, 1983; Belkacemi, Simoneau & Lafond, 2002; Belkacemi et al., 2004).
1552 A study on rats suggests that calbindin-D9K increases by over 100-fold in the last 7 days of
1553 gestation (Glazier et al., 1992), when the embryo gains the majority of calcium. *TRPV6* is
1554 involved with maternal-fetal calcium transport in mice (Suzuki et al., 2008). Increased *TRPV6*
1555 and calbindin-D28K expression occurs during eggshell formation in chickens (Yang et al.,
1556 2013). Given the involvement of these genes in both eggshell deposition and embryonic calcium
1557 transport, squamates may have exploited this pathway to support transitions. Expression of these
1558 genes during gestation or gravidity in squamates has been detected (e.g. calbindin-d9K in
1559 *Saiphos equalis*, and calbindin-d28k in *Zootoca vivipara*) (Foster et al., 2020; Recknagel et al.,
1560 2021a), and is expanded upon in the following paragraphs.

1561 In several highly matrotrophic lizards, embryonic uptake of calcium is associated with
1562 placental expression of calbindin-D28K (Stewart et al., 2009; Stinnett et al., 2011, 2012). In both
1563 oviparous and viviparous embryos of *Zootoca vivipara*, sharp increase in calcium uptake in late
1564 development coincides with increased calbindin-D28K and PMCA by the chorioallantois
1565 (Stewart et al., 2009, 2011). In oviparous corn snakes, *Pantherophis guttatus*, expression of
1566 calbindin-D28K in the yolk-sac and chorioallantoic membrane coincides with growth of these
1567 tissues and calcium transport activity (Ecay et al., 2004). The chorioallantois of other lizards and
1568 snakes transport calcium to the embryo and express calbindin-D28K and PMCA (Blackburn,
1569 2004; Ecay et al., 2004; Stewart et al., 2010; Stinnett et al., 2012).

1570 Viviparous embryos of *Zootoca vivipara*, a reproductively bimodal lizard, incubated *ex utero*
1571 respond to availability of calcium by increasing expression of calbindin-D28K (Ecay et al.,
1572 2017). In this species, embryonic recognition of environmental calcium stimulates a transcellular
1573 calcium transporting mechanism and may also alter chorioallantoic membrane paracellular
1574 permeability to calcium (Ecay et al., 2017). The authors proposed that there is a calcium sensing
1575 receptor (CaSR) on chorionic epithelial cells to support this in both oviparous and viviparous
1576 *Zootoca vivipara* embryos (Ecay et al., 2017), similar to the CaSRs expressed by vertebrate cells
1577 involved in calcium homeostasis (Brennan et al., 2013).

1578 As mentioned earlier, PMCA activity is associated with eggshell deposition in birds and
1579 oviparous squamates (Bar, Rosenberg, & Hurwitz, 1984; Hincke et al., 2012; Wasserman et al.,
1580 1991). PMCA is also crucial for calcium transport in late embryonic development in rats (Glazier
1581 et al., 1992). In viviparous scincid lizards, *Niveoscincus metallicus*, *N. ocellatus*, and
1582 *Pseudemoia spenceri*, PMCA was expressed in uterine glandular and surface epithelia during
1583 pregnancy but only *P. spenceri* expressed it throughout gestation (Herbert et al., 2006). When

1584 PMCA was not detected by immunoblotting in the yolk splanchnopleure of *Haldea striatula*, a
1585 viviparous snake that relies predominately on yolk calcium (Stewart, 1989; Fregoso, Stewart, &
1586 Ecay, 2010), NCXs were proposed as an alternative transporter of calcium (Fregoso et al., 2012).
1587 NCXs are important for placental calcium transport in humans (Belkacemi et al., 2005).

1588 Calcitropic hormones, those involved with calcium transport, and phosphotropic hormones,
1589 those involved with phosphorous transport, operate via an interconnected pathway (Andrukhova
1590 et al., 2016; Biber, Hernando & Forster, 2013; Blaine, Chonchol & Levi, 2015; Erben &
1591 Andrukhova, 2015). Phospho- and calcitropic hormones are important regulators of fetal serum
1592 mineral concentrations (Kovacs, 2015). Evidence from viviparous amniotes suggests that these
1593 are suitable candidates for embryonic calcium provisioning. In mice, genes encoding parathyroid
1594 hormone (*PTH*) and *PTH*-related peptide (*PTHrP*) are important regulators of placental calcium
1595 transport (Kovacs et al., 1996; Simmonds et al., 2010). A non-exhaustive list of additional
1596 candidates for embryonic calcium provisioning include fibroblast growth factor 23 (Bar, 2009a;
1597 Erben & Andrukhova, 2015; Stewart & Ecay, 2010), the annexin gene family (Matschke et al.,
1598 2006), carbonic anhydrase (Narbaitz et al., 1981; Tuan & Knowles, 1984), and calcium binding
1599 proteins (CaBPs) can be found in the referenced literature.

1600

1601 (4) *Discussion & future directions—calcium provisioning and parity mode evolution*

1602 Phylogenetic frameworks enable researchers to make broader testable hypotheses about the
1603 evolutionary history of calcium provisioning in specific clades. Such a framework is proposed in
1604 section V.2 to infer ancestral parity modes in the context of calcium provisioning in amniotes.
1605 Implications gleaned from taxon-specific studies can be explored in distantly related analogous
1606 groups.

1607 Genes involved with calcium transport in uterine and embryonic tissues have been described
1608 across mammals, birds, and reptiles. Like other amniotes, activity of calbindin-D28K and PMCA
1609 supports embryonic calcium provisioning across diverse oviparous and viviparous squamates.
1610 Their involvement with both eggshell deposition and embryonic calcium provisioning makes
1611 these particularly interesting candidates for parity mode evolution. The regulatory influence of
1612 other molecules in calcium transport, like *PTH*, *PTHrP* and NCXs has not been evaluated
1613 thoroughly in squamates. Additional reviews on mechanisms of embryonic calcium provisioning
1614 in squamates can be found in the literature (Stewart, 2013; Stewart & Eday, 2010).

1615 Additionally, I add a speculation. Perhaps lineages with incipient calcium matrotrophy more
1616 feasibly reverse to oviparity because of the continued role of the uterus in calcium provisioning.
1617 However, this hypothesis only holds up if maternal provisioning of calcium is not synonymous
1618 with maternal provisioning of all nutrients.

1619

1620 **VI. Maternal-Fetal Immune Dynamics**

1621

1622 Medawar (1953) pointed out the paradigm between the peripheral body's normal attack
1623 response to allografts (foreign tissue) and uterine tolerance to embryos (Medawar, 1953). This
1624 was inspired by earlier work by Ray Owen (Owen, 1945). Stricter regulation of the maternal and
1625 fetal immune systems is expected for viviparous reproduction because of contact between uterine
1626 and embryonic tissues. Oviparity may pose less of an immunological challenge. Medawar
1627 suggested barriers, inertness and/or immunosuppression enable pregnancy. This formed the
1628 foundation of decades of medical research on immune dynamics between maternal, embryonic,
1629 and paternal immune factors in utero.

1630 In recent years, there was a call for a reappraisal of Medawar's paradigm (Chaouat, 2010,
1631 2016; Moffett & Loke, 2004, 2006; Mor et al., 2011; Stadtmayer & Wagner, 2020b; Yoshizawa
1632 2016). Moffett & Loke (2006) caution against conceptualizing embryos as analogs of allografts.
1633 To my knowledge, this perspective has yet to reach the evolutionary literature on squamate
1634 parity mode evolution (Foster et al., 2020; Graham et al., 2011; Gao et al., 2019; Murphy &
1635 Thompson, 2011; van Dyke, Brandley, & Thompson, 2014; Murphy, Thompson, & Belov, 2009;
1636 Recknagel et al., 2021a). Importantly, challenges to Medawar's paradigm do not preclude
1637 immunological responses to viviparity. They simply suggest that the immune environment of the
1638 uterus is uniquely evolved to support exposure to foreign tissue.

1639 The uterine immune system has a distinct evolutionary history from the periphery. It enables
1640 cooperative dynamics with foreign tissues. It supports fertilization and early embryonic
1641 development. This should have started evolving, distinct from the periphery, since internal
1642 fertilization first originated. To contextualize this, I discuss the changing landscape of
1643 immunological research at the maternal-fetal interface and what it means in the context of
1644 amniote parity mode evolution. Overall, I hope readers consider how the uterus evolved to
1645 support internal gestation, and which model systems may be appropriate to investigate this.

1646 Most literature on maternal-fetal immune dynamics limits itself to mammals. Squamates may
1647 serve as a better comparative model for understanding the evolution of the uterine immune
1648 system. Active research on the peripheral reptilian immune system (Zimmerman et al., 2010,
1649 2020) and uterine immune activity in squamates (Graham et al., 2011; Hendrawan et al., 2017;
1650 Murphy et al., 2009; Paulesu et al. 1995, 2008, 2005) will support future insights on this.

1651

1652 *(1) Comparing amniote immune systems*

1653 Cellular components of the innate immune system are conserved across jawed vertebrates
1654 (Uribe et al., 2011; Zimmerman et al., 2010). The general machinery of the adaptive immune
1655 system is ancient despite divergences and convergences across all domains of life (Ghosh et al.,
1656 2011; Morales et al., 2017; Müller et al., 2018; Rimer et al., 2014). Diversification of antigen
1657 receptor genes likely occurred independently in a lineage-specific fashion (Boehm et al., 2018).
1658 Compared to mammals, the avian immune system requires less antigen (Larsson et al., 1998).
1659 Birds also have faster but shorter antibody responses, potentially due to their higher body
1660 temperatures (Zimmerman, 2010).

1661 Reptiles have the same general components of the mammalian immune system (Zimmerman,
1662 2020). However, the reptilian immune system may not fit neatly into the two arms of mammalian
1663 immune systems—innate and adaptive (Zimmerman, 2010; 2020). Expanding upon this is
1664 beyond the scope of this review, but it is worth considering in future evolutionary research.
1665 Squamates may serve as a better comparative model for understanding the evolution of the
1666 uterine immune system. Active research on the peripheral reptilian immune system (Zimmerman
1667 et al., 2010, 2020) and uterine immune activity in squamates (Graham et al., 2011; Hendrawan et
1668 al., 2017; Murphy et al., 2009; Paulesu et al. 1995, 2008, 2005) will support future insights. I
1669 refer readers to articles by Zimmerman et al. (2010, 2020) and Ghorai et al. (2018), and the book
1670 by Williams (2012) for more information on the avian immune system.

1671

1672 *(2) Medawar's paradigm*

1673 Tolerance toward the foreign fetus was postulated to occur through immunological inertness,
1674 immunosuppression or immunotolerance mechanisms (Medawar, 1953). Theoretically,
1675 immunotolerance could be established if there are relatively small quantities of alloantigens

1676 present, resulting in regulatory responses rather than activating responses (Pradeu, 2011).
1677 Contradicting this, the larger the alloantigen difference between the mother and embryo the
1678 bigger and healthier the placenta is in rats (Chaouat et al., 2010). In humans, divergent HLA
1679 profiles between mother and embryo do not lead to detrimental immune responses (Tilburgs,
1680 Scherjon, & Claas, 2010). Instead, cooperative inflammatory responses between maternal and
1681 fetal tissues support reproduction (Stadtmauer et al., 2020a). In humans, microchimeric cell
1682 populations, presence of cells from one individual in another genetically distinct individual, are
1683 now considered a normal expectation of pregnancy (Nelson, 2012).

1684 In his 1991 Nobel Lecture, Medawar acknowledged that maternal and embryonic tissues
1685 have regular exposure to alloantigens (Medawar, 1991). It has become clear that the maternal
1686 immune system actively responds to fetal alloantigen rather than responding solely with
1687 ignorance or anergy (Arck & Hecher, 2013). Neither maternal immunosuppression/privilege nor
1688 embryonic inertness/immaturity fully explain immune dynamics during gestation in mammals,
1689 including those with the simple epitheliochorial placentation (Chaouat et al., 2010; Chavan,
1690 Griffith & Wagner, 2017; Moffett & Loke, 2004, 2006; Stadtmauer & Wagner, 2020a).

1691

1692 *(3) Perspectives on the evolution of the uterine immune system*

1693 Viviparous reproduction existed eons before the origin of mammals and, to my knowledge,
1694 no evidence suggests there was immune conflict within these taxa (Chaouat, 2016). Placentrophy
1695 existed as far back as the invertebrate clade Bryozoa (Ostrovsky, 2013; Schwaha et al., 2019),
1696 suggesting an ancient history for supportive maternal-fetal immune dynamics. Differing from
1697 Medawar's paradigm, Polly Matzinger, who proposed the 'danger model' for the immune system

1698 (Matzinger, 2007), wrote “Reproduction cannot be a danger. It does not make evolutionary
1699 sense” (Chaouat, 2016).

1700 In mammals, immunological cells at the maternal-fetal interface may not function through
1701 self-non-self-discrimination, as they are understood to function in the rest of the body (Chaouat,
1702 2016; Moffett & Loke 2004, 2006). The ‘maternal-fetal interface’ may be better conceptualized
1703 as ‘maternal-fetal intra-action’ given the dynamics between maternal and fetal immune systems
1704 in mammals (Yoshizawa, 2016). It is unclear if these insights apply to other viviparous amniotes.

1705 In mammals, immune factors in the uterus and placenta appear to be specifically evolved to
1706 support maternal-fetal immune dynamics. Several cell types have unique functions and/or
1707 phenotypes in utero—uterine NK (uNK) cells, uterine macrophages, uterine T regulatory cells
1708 (Faas & de Vos, 2017; Mold et al., 2008, 2010; Mold & McCune, 2011). An immunosuppressive
1709 antigen, HLA-G, is almost exclusively expressed by trophoblasts (Faulk & Temple, 1976;
1710 Kovats et al., 1990; Rajagopalan & Long, 2012; Rouas-Freiss et al., 1997). Taken from an
1711 evolutionary perspective, this suggests that the uterine immune system in viviparous mammals
1712 evolved unique responses to allogenic tissues that differ from the periphery. Whether the
1713 evolution of this system predates mammals remains to be explored, to my knowledge.

1714 It is suggested that viviparous reproduction is immunologically compatible in species with
1715 less active adaptive immune system, like sharks (Chaouat, 2016). In these clades, innate immune
1716 cells, like uNK cells, may be sufficient to regulate immune responses during pregnancy (Moffett
1717 & Loke, 2004; Chaouat, 2016). Given that there is an unclear distinction between the innate and
1718 adaptive immune system in reptiles (Zimmerman, 2020), determining immunological difficulty
1719 of evolving viviparity in squamates requires further investigation.

1720 In uterine tissue of oviparous and viviparous skinks maternal antigens are expressed prior to
1721 and during gestation and gravidity (Murphy et al., 2009), but the viviparous species in the study
1722 have a unique expression profile of MHC antigens which may ‘hide’ the embryo from the
1723 maternal immune system (Murphy et al., 2009). Similarly, in a reproductively bimodal skink,
1724 *Saiphos equalis*, both oviparous and viviparous gestation is associated with expression of MHC
1725 genes (Foster et al., 2020). Regardless of parity mode, *S. equalis* expresses genes associated with
1726 immunocompetence, including MHC genes including *H2-EA* (Foster et al., 2020). The similar
1727 profile between the oviparous and viviparous state is attributed to the use of very long egg
1728 retention utilized by oviparous *S. equalis* (Foster et al., 2020). This highlights that extended
1729 embryonic retention is accompanied with immunological responses in utero, which is relevant to
1730 the EER model on amniote origins.

1731 Some of these genes expressed by *S. equalis* are also expressed in viviparous *Chalcides*
1732 *ocellatus* during gestation including complement component genes (C3, C9) and MHC genes
1733 (Brandley et al., 2012; Foster et al., 2020). The majority of immune genes expressed during
1734 gestation/gravidity in *S. equalis* have immunoglobulin receptor binding functions (Foster et al.,
1735 2020), an important feature of eutherian pregnancy that prevents rejection of the fetus through
1736 actions of the maternal innate immune system (Alijotas-Reig, Llorba, Gris, 2014)). In another
1737 reproductively bimodal skink, *Zootoca vivipara*, immune system response genes are enriched in
1738 the set of genes under divergent selection in oviparous and viviparous genomes (Recknagel et al.,
1739 2021a).

1740

1741 (4) *Implications of the reptilian immune system and morphology on parity mode evolution*

1742 Ectothermic reptiles may inherently have a more tolerogenic uterine environment compared
1743 to mammals due to their slower antibody response. It can take up to six weeks to reach peak
1744 concentrations (Ingram & Molyneux, 1983; Grey, 1963; Marchalonis et al., 1969; Pye et al.,
1745 2001; Origgi et al., 2001; Work et al., 2000). A slower metabolism also makes several reptiles
1746 more tolerogenic to pathogens (Ghorai & Priyam, 2018).

1747 During pregnancy in the viviparous skink, *Chalcides ocellatus*, there is a reduced response to
1748 in vitro exposure to mitogens concanavalin A (Con A), phytohemagglutinin (PHA), and
1749 *Escherichia coli* lipopolysaccharide (LPS) (Saad & El Deeb, 1990). Oviparous lizards exhibit
1750 immune activation tradeoffs during reproductive cycles (Cox, Peadar, & Cox, 2015; Durso &
1751 French, 2018; French, Johnston, & Moore, 2007; Uller, Isaksson, & Olsson, 2006).

1752 In the majority of viviparous squamates, the eggshell membrane is absorbed during
1753 pregnancy (Blackburn, 1993). In mammals, epitheliochorial placentation (the most superficial
1754 and non-invasive placenta type) is sufficient to cause immunorecognition from the mother.
1755 Specialized placental cells, trophoblasts, may be more common in other viviparous vertebrates
1756 than previously recognized (Blackburn, 2015a). For example, a gene with fusogenic properties
1757 characteristics of trophoblast syncytins was recently identified in the *Mabuya* lizard placenta
1758 (Cornelis et al, 2017). In mammals, trophoblasts are antigen presenting and actively participate
1759 in maternal-fetal immune dynamics.

1760 A few viviparous squamates have placentas with characteristics similar to placentas found in
1761 eutherian mammals—syncytialized cells layers, specialized zones such as areolae and
1762 placentomes, or cellular invasion of maternal tissues by the fetus (Blackburn & Flemming, 2012;
1763 Jerez & Ramírez-Pinilla, 2001; Vieira et al., 2007). The increased contact here may require more

1764 tightly regulated immune dynamics at the maternal-fetal interface compared to other viviparous
1765 squamates.

1766

1767 (5) *The inflammation paradox*

1768 In mammals, implantation evolved from an ancestral inflammatory attachment reaction
1769 (Griffith, Chavan et al., 2017). Inflammation is the most crucial system to support implantation,
1770 but it is also the greatest threat to the continuation of pregnancy (Chavan et al., 2017). This
1771 phenomenon is called the inflammation paradox. In humans, immune cells including uterine
1772 macrophages, T cells of multiple subtypes, uterine natural killer (uNK) cells, dendritic cells, and
1773 natural killer T (NKT) cells increase until implantation and remain abundant in the uterus
1774 throughout first trimester (Bulmer et al., 1991; Bulmer, Williams & Lash, 2010). Early
1775 implantation in humans is characterized by high pro-inflammatory T helper (Th)-1 cells and
1776 cytokines (IL-6, IL-8, and TNF α) (Yoshinaga, 2008). The exploitation of inflammatory
1777 mechanisms for eutherian implantation and the shift toward non-inflammatory activity to
1778 maintain pregnancy may have been key in enabling extended embryonic retention of eutherians
1779 (Griffith, Chavan et al., 2017).

1780 How the inflammation paradox applies to viviparous squamates is unclear, given that
1781 placentation in squamates and mammals is not homologous (Griffith, Van Dyke, & Thompson,
1782 2013). In extrauterine pregnancies of mammals with non-invasive placentas, the embryo will
1783 invade extrauterine tissue because it is not inhibited by uterine secretions (Vogel, 2005; Samuel
1784 & Perry, 1972). However, in *Pseudemoia entrecasteauxii*, a viviparous skink that also has a non-
1785 invasive placenta, extrauterine pregnancy does not result in invasive implantation of extrauterine
1786 tissues (Griffith, Van Dyke, & Thompson, 2013). The inherent invasive nature of mammalian

1787 embryos outside of the uterus, compared to the non-invasive nature of viviparous squamate
1788 embryos studied thus far, suggests that the parent-offspring conflict and the inflammation
1789 paradox may be less pronounced in viviparous squamates compared to viviparous mammals.

1790

1791 *(6) Inertness and barriers at the maternal-fetal interface*

1792 The uterine environment is not inert or sterile (Agostinis et al., 2019; Erlebacher, 2013;
1793 Moffett & Loke, 2006; Munoz-Suano, Hamilton, & Betz, 2011; Murphy, Thompson, & Belov,
1794 2009; Yoshimura, Okamoto, & Tamura, 1997). In humans, the decidual layer of the uterus
1795 during pregnancy is comprised of ~40% leukocytes (Ander, Diamond, & Coyne, 2019; Manaster
1796 & Mandelboim, 2010). This cellular subpopulation has 70% uNK cells, 10-20% antigen
1797 presenting cells (APCs) including macrophages and dendritic cells, and 3-10% T cells of several
1798 subtypes (Abrahams et al., 2004; Hanna et al., 2006; Kämmerer et al., 2006; Le Bouteiller &
1799 Piccinni, 2008; Liu et al., 2017; Manaster & Mandelboim, 2010; Moffett-King, 2002; Moffett &
1800 Loke, 2006; Roussev et al., 2008). There is an abundance of decidual large granular lymphocytes
1801 (LGLs), CD3-NK cells and CD3+ activated cytotoxic T cells, in the human uterus, that have
1802 cytotoxic properties and produce cytokines, and these are affected by fetal MHC molecules
1803 (Rieger, 2002).

1804 Birds also have immunocompetent cells in their oviducts. T and B cells are present in
1805 chicken ovary where they are stimulated by estrogen (Barua & Yoshimura, 1999; Withanage et
1806 al., 2003; Zettergren & Cutlan, 1992). Other immunocompetent cells in the chicken oviduct
1807 include IgG+, IgA+ and CD3+ (Yoshimura, Okamoto, & Tamura, 1997). Immune competent
1808 cells located throughout the mucosal tissue of avian oviductal segments including macrophages,

1809 antigen presenting cells (APCs) expressing MHC class II antigens, helper T cells and cytotoxic T
1810 cells, and premature B cells (Das, Isobe, & Yoshimura, 2008).

1811 Inert barriers between maternal and fetal tissues may 'hide' the embryo. In oviparous taxa,
1812 the eggshell may serve as a barrier. However, the antimicrobial properties of the eggshell matrix
1813 in birds demonstrate that even the eggshell is not inert. The FAS ligand, also called APO-1 or
1814 CD95, in humans and rodent embryonic tissue was proposed to serve as a barrier because it
1815 causes apoptosis of surrounding maternal immune cells (Kayisli et al., 2003; Makrigiannakis et
1816 al., 2008).

1817 Medawar suggested that an impermeable placenta strictly regulates molecular exchanges,
1818 preventing rejection of the embryo (Medawar, 1991). Syncytiotrophoblasts lack cellular junctions
1819 and thus it was postulated to serve as this barrier (Ander et al., 2019). However, the growing data
1820 on bidirectional cellular traffic of APCs, even in mammals with noninvasive placentas, rejected
1821 this hypothesis (Bakkour et al., 2014; Burlingham & Bracamonte-Baran, 2015; Fujiki et al.,
1822 2008; Turin et al., 2007).

1823

1824 *(7) T cell populations and mammalian viviparity*

1825 In mammals, immune-dynamics at the maternal-fetal interface are established through
1826 innate and adaptive immune responses. There is a delicate balance between ratios of Th1, Th2,
1827 Th17, Tregs and memory T cells at the maternal-fetal interface in eutherian mammals during
1828 gestation (Chaouat et al., 1997; Kieffer et al., 2019; Peck & Mellins, 2010; Saito et al., 2010; Wu
1829 et al., 2014). A shift in utero from T helper type 1 (Th1) cells to T helper type 2 (Th2) cells
1830 during gestation in mammals equates to a shift from pro-inflammation to anti-inflammation. The
1831 galectin proteins, GAL-13 and GAL-14, expressed by syncytiotrophoblasts, bind to T cells

1832 where they inhibit activation, induce apoptosis, and enhance interleukin-8 (IL-8) production
1833 (Balogh et al., 2019).

1834 Growing research is revealing the central role of Tregs at the maternal-fetal interface
1835 during pregnancy in mammals (Teles et al., 2013; Wienke et al., 2019). Tregs play a central role
1836 in immunosuppression in mammals (Attias, Al-Aubodah, & Piccirillo, 2019). Differentiation of
1837 Tregs is governed by the transcription factor, *FOXP3* (Ramsdell & Rudensky, 2020).

1838 Alloantigen-dependent, uterine T cell signaling, and immunocompetent embryonic cells and their
1839 products facilitate enhanced regulatory phenotypes of immune cells overall (Ander et al., 2019).

1840 The T-cell dependent adaptive immune system of mammals is unique. This may have
1841 prompted their intricate balance of Treg mediators of immunotolerance at the maternal-fetal
1842 interface (Chaouat, 2016). Birds rely more heavily on B cells. In non-avian reptiles, T helper
1843 cells are functional, but the presence and function of other T cell subsets is unclear (Zimmerman,
1844 2020; Zimmerman, Vogel, & Bowden, 2010). The potential role of T cells and Tregs in
1845 viviparous squamate gestation should not be discounted. Treg-like cells have been identified in a
1846 pufferfish, *Tetraodon nigroviridis* (Wen et al., 2011), suggesting that Tregs may have an ancient
1847 evolutionary history.

1848

1849 *(8) Progesterone, cytokines, and maternal-fetal immune dynamics*

1850 In addition to the role of progesterone in uterine quiescence (embryonic retention) and
1851 hepatic vitellogenesis (nutrient provisioning), it also plays a role in maternal-fetal immune
1852 dynamics. In the uterus of pregnant mammals, progesterone concentrations are associated with
1853 altered B cell immunoglobulin secretion, inhibition of NK-cell mediated cytotoxicity and the shift
1854 from Th1 (pro-inflammatory) to Th2 (anti-inflammatory) dominated immune responses

1855 (Druckmann & Druckmann, 2005). Progesterone is also associated with immunomodulatory
1856 effects (Ortega Brown et al., 1990). During gestation in *Agkistrodon piscivorus*, a viviparous pit
1857 viper, progesterone concentrations are associated with decreased complement performance
1858 (Graham et al., 2011), a portion of the immune system that promotes inflammation, among other
1859 immune functions.

1860 In humans, progesterone induced protein (PIBF) is transported by placental extravillous
1861 trophoblasts to maternal lymphocytes causing the induction of interleukin-10 (IL-10) production,
1862 contributing to the Th2 dominant responses (Szekeres-Bartho, Šučurović, & Mulac-Jeričević,
1863 2018). IL-10 is a potent anti-inflammatory cytokine that is produced by multiple cell types
1864 (Zimmerman, Bowden, & Vogel, 2014). It is associated with Th2 response, and it inhibits Th1
1865 responses. The phenotype of uterine macrophages is affected by trophoblasts when they secrete
1866 IL-10 and macrophage colony-stimulating factor (M-CSF) (Svensson-Arvelund et al., 2021). IL-
1867 10 inhibits IFN- γ and increases in response to infection in chickens (Giansanti, Giardi, & Botti,
1868 2006; Rothwell et al. 2004). In the uterus of the oviparous skink, *Lampropholis guichenoti*,
1869 during gravidity and non-gravidity, IL-10 is expressed (Griffith et al., 2016).

1870 Proinflammatory cytokines may be downregulated during reproductive periods to limit
1871 maladaptive immune responses to the foreign fetus (Zimmerman, Vogel, & Bowden, 2010). In
1872 mammals, IL-1 allows release of hormones in human trophoblasts (Petraglia et al., 1990;
1873 Masuhiro et al., 1990; Yagel et al., 1989), facilitates implantation (Haimovici, Hill, & Anderson,
1874 1991; Hill, 1992; Tartakovsky & Ben-Yair, 1991), and influences the initiation of labor (Romero
1875 et al., 1989, 1992). Regulation of the proinflammatory cytokines tumor necrosis factor (TNF)
1876 and interleukin 1B (IL-1 β) is of particular importance in eutherian pregnancy (Haider & Knöfler,
1877 2009; Paulesu, Romagnoli, & Bigliardi, 2005; Saito et al., 2010; Tayade et al., 2006).

1878 The uterine tissue of two reproductively bimodal squamates—viviparous individuals of
1879 *Chalcides chalcides*, and oviparous and viviparous individuals of *Zootoca vivipara*—express IL-
1880 1β (Paulesu et al., 1995, 2005; Romagnoli et al., 2003). In the uterus of the viviparous skink,
1881 *Pseudemoia entrecasteauxii*, during gestation regulation of TNF and IL- 1β at the transcriptional
1882 and post-translation levels, respectively, may reduce inflammation (Hendrawan et al., 2017). The
1883 pro-inflammatory function of IL- 1β in *Pseudemoia entrecasteauxii* may play a role developing a
1884 more complex placenta (Hendrawan et al., 2017). The placenta of *Chalcides chalcides* expresses
1885 pro-inflammatory cytokines, IL- 1α and IL- 1β , at specific times during gestation (Paulesu et al.,
1886 1995). During gestation, *Chalcides ocellatus* also differentially expresses 27 other interleukins
1887 and interleukin related products (Brandley et al., 2012).

1888 The expression of IL-34 in a marsupial, the fat-tailed dunnart, during pre-implantation
1889 (Whittington et al., 2018) may have an immunosuppressive function to help tolerate potential
1890 contact of maternal and fetal tissues when the embryonic shell coat disintegrates (Lindau et al.,
1891 2015). In chickens, IL-34 regulates Th1 and Th17 cytokine production (Truong et al., 2018).
1892 During gestation in *Pseudemoia entrecasteauxii*, IL-16 and IL- 1α are expressed in addition to
1893 three receptors for Th17 family cytokines—IL-17RA, IL-17RC, and IL-17RA (Griffith,
1894 Brandley, et al., 2016, 2017). In the yolk sac of *Pseudemoia entrecasteauxii* during pregnancy
1895 interleukin related molecules, *ILDR1*, *IRAK1*, and *SIGIRR*, are differentially expressed (Griffith
1896 et al., 2016). This profile suggests the presence of tricellular tight junctions and/or tricellulin
1897 (Higashi et al., 2013; Ikenouchi et al., 2005), and regulation of toll-like receptors (TLRs) and/or
1898 IL-1R signaling (Kawagoe et al., 2008; Lin, Lo, & Wu, 2010; Muzio et al., 1997).

1899

1900 (9) *The major histocompatibility complex and maternal-fetal immune dynamics*

1901 A substantial amount of literature on maternal-fetal immune dynamics was focuses on uNK
1902 cells. Uterine NK cells have a distinct phenotype and function from peripheral NK cells. They
1903 have several activating receptors (Manaster & Mandelboim, 2010) but do not exert cytolytic
1904 functions on embryonic trophoblasts that they are in contact with (King, Birkby, & Loke, 1989).
1905 Allorecognition of embryonic placental cells by uNK cells is a key regulator of the maternal-fetal
1906 immune mechanisms that support placentation in mammals (Moffett & Colucci, 2014). When
1907 cells lose their ability to express any HLAs, uNK cells are shown to kill them (Hunt et al., 2005;
1908 Ishitani et al., 2003; King, Allen et al., 2000).

1909 In humans, expression of the classical MHC class I (C-MHCI) molecule HLA-C, and
1910 nonclassical MHC class I (NC-MHCI) molecules HLA-E, HLA-F and HLA-G on trophoblasts
1911 inhibit uNK cell-mediated cytotoxicity (Hunt et al., 2003; King, Burrows et al., 2000). Differing
1912 from this, mismatched HLA-C profiles trigger rejection of the transplanted organs (Petersdorf et
1913 al., 2014). Selection for balanced polymorphisms in HLA-C alleles and their killer
1914 immunoglobulin receptors (KIRs) is proposed to be driven by reproductive success, rather than
1915 immune recognition of pathogens (Trowsdale & Betz, 2006). Dimorphisms of HLA-C emerged
1916 recently within primates (Adams & Parham, 2001).

1917 Similar patterns in MHC profiles have been explored in other viviparous amniotes. C-MHCI
1918 antigen, H2-K, is expressed on giant trophoblast cells of mice and this is attributed to
1919 trophoblast-induced uterine vasculature transformation (Arcellana-Panlilio & Schultz, 1994;
1920 Chatterjee-Hasrouni & Lala, 1982; Hedley et al., 1989; King et al., 1987; Sellens, Jenkinson, &
1921 Billington, 1978). H2-D antigen is co-expressed with H2-K in virtually all their other nucleated
1922 cells (Madeja et al., 2011). However, H2-K expressing trophoblasts lack H2-D expression. This

1923 parallels the expression patterns of C-MHC molecules at the maternal-fetal interface in humans
1924 and may be an evolutionarily conserved pattern (Madeja et al., 2011).

1925 In humans, NC-MHCI molecule, HLA-G, is especially tolerogenic (Carosella et al., 2015;
1926 González et al., 2012; Hviid et al., 2004; Kovats et al., 1990). In adults, HLA-G is almost
1927 exclusively expressed by fetal trophoblasts compared to adult cells (Faulk & Temple, 1976;
1928 King, Burrows et al., 2000; Kovats et al., 1990; Rajagopalan & Long, 2012; Rouas-Freiss et al.,
1929 1997). It supports immunotolerance at the maternal-fetal interface (Rebmann et al., 2014). The
1930 role of HLA-G in supporting tolerogenic responses to organ transplants appears to be an
1931 exploitation of its role in immunotolerance in the utero during pregnancy (Rebmann et al., 2014).
1932 HLA-G is upregulated by several molecules that serve essential roles during gestation including
1933 progesterone (Yie, Xiao, & Librach, 2006; Yie et al., 2006), IFN- α , IFN- β , and IFN- γ (Rebmann
1934 et al. 2003; Lefebvre et al., 2001; Ugurel et al., 2001; Yang, Geraghty, & Hunt, 1995), and IL-10
1935 and TGF- β (Cadet et al., 1995; Moreau et al., 1999).

1936 A similar NC-MHCI gene to HLA-G exists in horses (Davies et al., 2006) where it likely
1937 functions to protect the embryo from NK-cell mediated attack (Ott et al., 2014). NC-MHC
1938 molecules with similar structure to HLA-G are also found in Rhesus monkeys (Boyson et al.,
1939 1997) and baboons (Stern et al. 1987). Mice have two NC-MHCI genes that are expressed on the
1940 surface of their placentas and on pre-implanted embryos (Sipes et al., 1996).

1941 In the gestating uterus of the viviparous skink, *Pseudemoia entrecasteauxii*, four putative C-
1942 MHCI and two putative NC-MHCI molecules are expressed (Murphy, Thompson, & Belov,
1943 2009). This pattern resembles the C-MHCI and NC-MHCI expression profiles of mammals,
1944 suggesting that this viviparous skink utilizes a similar physiological mechanism to ‘hide’ the
1945 embryo (Murphy, Thompson, & Belov, 2009). One of the putative NC-MHCI genes (Psen-

1946 160Ut/Psen-78G) has a substitution at position 150 where a tryptophan is substituted for a
1947 leucine (Murphy, Thompson, & Belov, 2009). When Psen-160Ut/Psen-78G was aligned to NC-
1948 MHC I genes of vertebrates ranging from fish to eutherian mammals, tryptophan was conserved
1949 at position 150 except in Psen-160Ut/Psen-78G and HLA-G (Murphy, Thompson, & Belov,
1950 2009). Whether this reflects an evolutionary history associated with immune tolerance at the
1951 maternal-fetal interface in *Pseudemoia entrecasteauxii* requires further investigation.

1952 MHC I genes are also expressed in reproductive tissues of oviparous skinks (*Ctenotus*
1953 *taeniolatus* and *Lampropholis guichenoti*) during non-reproductive periods and during late
1954 gravidity (Murphy, Thompson, & Belov, 2009). A similar pattern is found in viviparous skinks
1955 *Eulamprus tympanum*, *Niveoscincus metallicus*, *Pseudemoia entrecasteauxii* and the
1956 reproductively bimodal skink *Saiphos equalis* which all express MHC I genes at non-
1957 reproductive periods and during late pregnancy/gravidity (Murphy, Thompson, & Belov, 2009).
1958 MHC gene H2-EA is also expressed during gestation with long egg retention in *Saiphos equalis*.

1959 The butyrophilin subfamily 1 member A (*BTN1A1*) is located in the MHC I region of the
1960 genome in mammals (Trowsdale, 2011). *BTN1A1* is differentially expressed in the uterus during
1961 gestation in a viviparous lizard, *Chalcides ocellatus* (Brandley et al., 2012). *BTN1A1* may have
1962 important antimicrobial properties in chicken eggshells (Mann, Maček, & Olsen, 2006). In
1963 mammals *BTN1A1* is the major protein associated with fat droplets in milk (Jeong et al., 2009).

1964

1965 (10) *Microchimerism and maternal-fetal immune dynamics*

1966 Billingham, Brent and Medawar suggested the concept of actively acquired immunologic
1967 tolerance during pregnancy 70 years ago (Billingham, Brent, & Medawar, 1953; Ribatti, 2015).
1968 Subsequent research over the following decades revealed that substantial transfer of proteins,

1969 parasites and even immunologically active cells occurs between mother and embryo (Adams &
1970 Nelson, 2004; Axiak-Bechtel et al., 2013; Bakkour et al., 2014; Burlingham, 2010; Fujiki et al.,
1971 2008; Gitlin et al., 1965; Khosrotehrani et al., 2005; Owen, 1945; Turin et al., 2007).
1972 Microchimerism, where there is <0.1% donor chimeras in host tissue, is relatively pervasive
1973 among eutherians during pregnancy. It plays a role in establishing tolerance to non-inherited
1974 antigens. For example, cell populations from the mother that are transferred into embryonic
1975 lymph nodes enable the establishment of embryonic Tregs that are tolerogenic toward non-
1976 inherited maternal antigens (Mold et al., 2008).

1977 Microchimeric cellular populations are transferred across all placental types (Axiak-Bechtel
1978 et al., 2013; Bakkour et al., 2014; Fujiki et al., 2008; Khosrotehrani et al., 2005; Turin et al.,
1979 2007). Fetal and maternal cells persist for decades after birth across a range of tissues in mother
1980 and offspring, respectively (Adams & Nelson, 2004; Bakkour et al., 2014; Bayes-Genis et al.,
1981 2005; Bianchi et al., 1996; Evans et al., 1999; Jonsson et al., 2008; Stevens et al., 2004). There is
1982 even a call in the immunology literature to shift from the conventional paradigm of “self vs
1983 other” to instead consider the “self” as inherently chimeric (Nelson, 2012). Given that
1984 epitheliochorial placentation is sufficient to illicit microchimeric cell populations, the occurrence
1985 of similar bidirectional cellular traffic is a reasonable possibility in viviparous squamates.

1986

1987 (11) *Paternal alloantigens*

1988 Under tenants gleaned from transplant medicine, the maternal immune system would illicit
1989 an attack response as early as insemination when maternal tissues are exposed to paternal
1990 alloantigens (Borziak et al., 2016; Schumacher & Zenclussen, 2015; Seavey & Mosmann, 2006).
1991 Instead, maternal cells immunologically recognize them at this time without attack (Schumacher

1992 & Zenclussen, 2015; Seavey & Mosmann, 2006; Zenclussen et al., 2010). Treg expansion, a
1993 process with major influence on maternal-fetal immunotolerance in mammals, is proposed to be
1994 driven by several different factors found in seminal plasma (Baratelli et al., 2005; Teles et al.,
1995 2013). Mothers may maintain fetal-specific Tregs with memory of the paternal alloantigens
1996 (Zenclussen et al., 2010), expediting Treg response in future pregnancies with the same father
1997 (Rowe et al., 2012).

1998 Alloantigen exposure at the time of insemination is not restricted to mammals. Seminal fluid
1999 of chickens contains two MHC I paternal alloantigens and one MHC II alloantigen (Borziak et
2000 al., 2016). It also contains proteins involved in immunity and antimicrobial defenses (Borziak et
2001 al., 2016). In hens, evidence suggests that a protective local immunity to pathogens is established
2002 after exposure to semen but the mechanisms for this remain unclear (Reiber & Conner, 1995;
2003 Reiber, Conner, & Bilgili, 1995).

2004 In mammals, paternal alloantigens and cytokines in seminal fluid drive immune tolerance
2005 (Schjenken & Robertson, 2014). Mammalian seminal plasma contains immune-factors (Kelly,
2006 1995; Schjenken & Robertson, 2014)—TGF- β (Breuss et al., 1993; Chu & Kawinski, 1998;
2007 Slater & Murphy, 1999), IL-8 (Gutsche et al., 2003), and soluble IL-2 receptor (Srivastava,
2008 Lippes, & Srivastava, 1996), prostaglandin E2 (PGE2) and 19-hydroxyprostaglandin E (19-
2009 hydroxy PGE) (Denison et al., 1999), soluble tumor necrosis factor (TNF) receptors (Liabakk et
2010 al., 1993), receptors for the Fc portion of γ -globulin, spermine (Evans, Lee, & Flugelman, 1995),
2011 and complement inhibitors (Kelly, 1995). In horses and pigs, respectively, the proteins CRISP3
2012 (Doty et al., 2011), PSP-I and PSP-II (Rodriguez-Martinez et al., 2010), act as signaling agents
2013 in seminal fluid.

2014 Secretions of growth factors, cytokines and chemokines from cervical and endometrial
2015 tissues immediately following insemination generates a proinflammatory environment that likely
2016 aids in implantation. In the utero-vaginal junction of chickens and the utero-tubal junction of
2017 pigs, expression of several genes were shared following mating compared to non-mating and
2018 these genes were involved with immune-modulation (*IFIT5*, *IFI16*, *MMP27*, *ADAMTS3*, *MMP3*,
2019 *MMP12*) and pH-regulation (*SLC16A2*, *SLC4A9*, *SLC13A1*, *SLC35F1*, *ATP8B3*, *ATP13A3*), a
2020 process essential for implantation (Atikuzzaman et al., 2017, 2015). Instead of mounting an
2021 attack, it appears that the uterine immune system and paternal genes work cooperatively to
2022 support pregnancy in mammals and gravidity in birds. Whether this applies to reptiles, and how
2023 it may influence immune dynamics involved with squamate parity mode evolution, deserves
2024 investigation.

2025

2026 (12) *Discussion and future directions—maternal-fetal immune dynamics & the*
2027 *evolution of parity modes*

2028 Immune processes appear to be important for both oviparity and viviparity—as evidenced
2029 here, in part, by overlapping expression profiles of immune genes in female reproductive tissues
2030 of chickens and pigs, expression of paternal antigens in avian seminal fluid, and uterine
2031 expression of maternal antigens in oviparous and viviparous skinks. This highlights the scientific
2032 advances made since Medawar’s paradigm, when embryos were treated as analogs to allografts.
2033 Nonetheless, viviparity is associated with complex immune dynamics between maternal, fetal,
2034 and paternal tissues.

2035 Overall, evolving appropriate immunological responses is one hurdle of transitions to
2036 viviparity in squamates. This is evidenced by the unique MHC expression profiles identified in

2037 some viviparous skinks compared to oviparous relatives (Murphy et al., 2009); and the detection
2038 of divergent selection in immune response genes in viviparous and oviparous *Zootoca vivipara*
2039 (Recknagel et al., 2021a). Labile parity modes in squamates may be supported if they are more
2040 heavily reliant on the innate immune system for reproduction. However, reptiles may not have
2041 distinguished innate and adaptive immune systems (Zimmerman et al., 2020).

2042 Changes to genes that serve overlapping functions across the Main Five may have a
2043 disproportionate influence on transitions between parity modes. In this section I reviewed two
2044 molecules, *TGF-β* and progesterone, that exert influence on multiple Main Five categories.
2045 Progesterone influences uterine quiescence (embryonic retention), hepatic vitellogenesis
2046 (nutrient provisioning) and regulation of inflammatory responses in utero (maternal-fetal
2047 immune dynamics). Genes in the *TGF-β* family play a role in placental development and
2048 maternal-fetal immune dynamics. *TGF-β* family is implicated in placental development in
2049 eutherians (Hempstock et al., 2004; Caniggia et al., 2000; Lafontaine et al., 2011). A *TGF-β*
2050 receptor protein (*TGFBR1*) was associated with placental development in *Phrynocephalus*
2051 *vlangalii* (Gao et al., 2019). In humans *TGF-β* upregulates tolerogenic HLA-G in utero and is an
2052 immune factor in mammalian seminal fluid. Multiple genes in the *TGF-β* family are also
2053 differentially expressed during gestation in other viviparous lizards, *Pseudemoia entrecasteauxii*
2054 and *Saiphos equalis* (Foster et al., 2020; Griffith et al., 2016). Examining the functions of *TGF-β*
2055 and progesterone across other amniotes may reveal insights into how these molecules influence
2056 the evolution of parity modes.

2057 In mammals, inflammation appears to be involved with two of the Main Five processes—
2058 regulation of maternal-fetal immune dynamics and embryonic retention. It is intriguing to
2059 consider the implications this has for the interconnectedness of the Main Five. Greater

2060 interconnectedness would suggest that changes to few genes involved with the Main Five could
2061 cause a cascading effect to support more labile transitions between parity modes.

2062 Implantation and parturition in therian mammals evolved from a shared inflammatory
2063 attachment reaction (Hansen et al., 2017). The process of implantation has important
2064 implications for maternal-fetal exchanges of inorganic and organic material and maternal-fetal
2065 immune dynamics. Given that inflammation is associated with implantation and parturition
2066 implicates it in gas, water, and nutrient provisioning (including calcium here), maternal-fetal
2067 immune dynamics and length of embryonic retention. However, implantation in mammals and
2068 viviparous squamates is not homologous (Griffith, Van Dyke, & Thompson, 2013). Therefore, it
2069 is difficult to make inferences about how substantial the influence of inflammation is on the
2070 evolution of parity modes in squamates. Nonetheless, the abundant literature on uterine
2071 inflammatory processes during human pregnancy and the evolution of inflammatory processes
2072 that supported the evolution of viviparity in mammals (Challis et al., 2009; Chavan, Griffith, &
2073 Wagner, 2017; Mor et al., 2011; Griffith, Chavan et al., 2017; Stadtmauer & Wagner, 2020a)
2074 serve as indispensable resources for exploring the role of inflammation in squamate viviparity. I
2075 resist expanding on this further. I suspect that the immune system plays a central role in dictating
2076 the plasticity of parity modes. However, further work is necessary to validate this.

2077

2078

2079 **VII. Conclusions**

2080

2081 (1) Through holistic consideration of the unique complexity of parity mode evolution, within
2082 the context of genomic and transcriptomic studies across interdisciplinary fields, this

2083 review provided a new perspective on the history of parity mode transitions in amniotes
2084 and squamates. The overlapping activity of immune genes in utero, genes for calcium
2085 transport, placentation, and hormonal regulation across mammals, birds, and reptiles hint
2086 at discoveries to be made. There is a fascinating history to the evolutionary physiology
2087 and genomics of reproduction in amniotes that is ripe for downstream research.

2088 (2) Changes to gene(s) or physiological processes associated with more than one of the Main
2089 Five should disproportionately influence parity mode evolution—*SLC* gene superfamily,
2090 TGF- β , *BMPRI*B, progesterone, *PMCA*, calbindin-D28K, *SPP1*, sustained functioning of
2091 the corpora lutea and inflammation, and the genes associated with both gestation length
2092 and eggshell traits in *Zootoca vivipara* (Recknagel et al., 2021a).

2093 (3) Growing evidence in the medical literature suggests that immune system interactions at
2094 the maternal-fetal interface in mammals did not evolve simply through tolerance,
2095 evasion, or suppression (Chaouat, 2016; Chavan, Griffith, & Wagner, 2017; Moffett &
2096 Loke, 2004, 2006). Instead, maternal-fetal immune dynamics have a deep evolutionary
2097 history that enables both embryo and mother interact cooperatively (Yoshizawa, 2016).
2098 Future research on amniote parity mode evolution should consider maternal-fetal immune
2099 dynamics in this context. Nonetheless, viviparity and extended embryonic retention are
2100 assuredly associated with immunological responses in squamates (e.g. Foster et al.,
2101 2020).

2102 (4) Compared to viviparous endothermic amniotes, ectothermy likely influences parity mode
2103 evolution differently because it entails slower antibody responses and a greater reliance
2104 on climatic conditions for embryonic development. This and the Cold Climate
2105 Hypothesis are likely relevant to the origin of the amniotic egg and squamate parity mode

2106 evolution. Climatic shifts during the origin of amniotes should be explored for their
2107 consistency with the EER model.

2108 (5) Two new mechanisms for transitions between oviparity and viviparity, without
2109 necessitating intermediate stages, stand out from the cumulative research on the Main
2110 Five. These are presented here (Conclusions 6 and 7) as tools to be broadened and
2111 challenged with the goal of advancing scientific insight on the subject.

2112 (6) The genomics and physiology of amniote parity mode evolution does not preclude an
2113 origin of viviparity in the MRCA of Lepidosauria. I propose the following mechanism—a
2114 change to the phenotype or function of mammillary knobs occurred in the MRCA of
2115 Lepidosauria, instantaneously preventing calcium carbonate deposition (basal cap
2116 hypothesis); the eggshell loss enabled uterine exposure to chorioallantoic progesterone
2117 production (extending embryonic retention) and incipient calcium matrotrophy
2118 (supporting embryonic development); parturition occurred via 1) placental progesterone
2119 withdrawal or 2) overdistension of the uterus triggers contractions. This is one way to
2120 imagine viviparity evolving in the MRCA of Lepidosauria.

2121 a. Hypothesis testing: If the genes that code for the KS-proteoglycan, “mammillan”,
2122 that makes up mammillary knobs are absent or non-functional across squamates
2123 and tuatara, then this would support the basal cap hypothesis. To test this
2124 hypothesis, the genes must be identified in Archelosaur genomes and proteomes.
2125 Additionally, ancestral state reconstructions on the eggshell and eggshell
2126 membrane should be generated across oviparous and viviparous Archelosaurs,
2127 utilizing current recommendations for characterizing eggshell microstructure

2128 (Legendre et al., 2022). This will require also developing a system to accurately
2129 characterize eggshell membranes.

2130 (7) As discussed, the calcium secreting capacity of the uterus is maintained in oviparous
2131 viviparous squamates. Nonetheless, a reversal back to oviparity may evolve most easily
2132 within viviparous clades with matrotrophic calcium provisioning through the following
2133 sequence of events—calcium secretions in utero stick to the eggshell membrane instead
2134 of being absorbed by the chorioallantois; oviposition can then occur early in embryonic
2135 development in one of two ways 1) the death of corpora lutea or 2) the calcified eggshell
2136 blocks a threshold of chorioallantoic progesterone production from reaching uterine
2137 tissue; the calcified eggshell provides embryonic calcium that is transported upon
2138 embryonic metabolic demand.

2139 a. Hypothesis testing: Recent reversals should have physiological or genomic
2140 remnants of a viviparous past. Given that viviparous squamates generally have
2141 more active uterine immune systems to support gestation, oviparous reversals
2142 should 1) have more immune genes expressed in utero than ancestrally oviparous
2143 squamates, and 2) these immune genes should have stronger signatures of relaxed
2144 selection than immune genes expressed in a close relative during viviparous
2145 gestation.

2146
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2153 **IX. References**

- 2154
- 2155 Abrahams, V. M., Y. Mee Kim, S. L. Straszewski, R. Romero, and G. Mor. (2004).
2156 Macrophages and Apoptotic Cell Clearance during Pregnancy. *American Journal of*
2157 *Reproductive Immunology* **51**(4), 275–82.
- 2158 Adams, S. M., J. M. Biazik, M. B. Thompson, and C. R. Murphy. (2005). Cyto-Epitheliochorial
2159 Placenta of the Viviparous Lizard *Pseudemoia entrecasteauxii*: A New Placental
2160 Morphotype *Journal of Morphology* **264**(3), 264–76.
- 2161 Adams, K. M., and J. L. Nelson. (2004). Microchimerism: An Investigative Frontier in
2162 Autoimmunity and Transplantation. *Journal of the American Medical Association* **291**(9),
2163 1127–31.
- 2164 Adams, A. P., J. G. Oriol, R. E. Campbell, Y. C. Oppenheim, W. R. Allen, and D. F. Antczak.
2165 (2007). The Effect of Skin Allografting on the Equine Endometrial Cup Reaction.
2166 *Theriogenology* **68**(2), 237–47.
- 2167 Adams, E. J., and P. Parham. (2001). Species-specific evolution of MHC class I genes in the
2168 higher primates. *Immunological Reviews* **183**, 41-64.
- 2169 Adams Waldorf, K. M., N. Singh, A. R. Mohan, R. C. Young, L. Ngo, A. Das, J. Tsai, et al.
2170 (2015). Uterine Overdistention Induces Preterm Labor Mediated by Inflammation:
2171 Observations in Pregnant Women and Nonhuman Primates. *American Journal of*
2172 *Obstetrics and Gynecology* **213**(6), 830.E1—830.E19

- 2173 Agostinis, C., A. Mangogna, F. Bossi, G. Ricci, U. Kishore, and R. Bulla. (2019). Uterine
2174 Immunity and Microbiota: A Shifting Paradigm. *Frontiers in Immunology* **10**
- 2175 Albergotti, L. C., and L. J. Guillette. (2011). Viviparity in Reptiles: Evolution and Reproductive
2176 Endocrinology. Hormones and Reproduction of Vertebrates. In D. O. Norris and K. H.
2177 Lopez (Eds.), *Hormones and Reproduction of Vertebrates* (pp. 247-275). Academic
2178 Press.
- 2179 Alföldi, J., F. di Palma, M. Grabherr, C. Williams, L. Kong, E. Mauceli, P. Russell, et al. (2011).
2180 The Genome of the Green Anole Lizard and a Comparative Analysis with Birds and
2181 Mammals. *Nature* **477**(7366), 587–91.
- 2182 Alijotas-Reig, J., Llurba, E., & Gris, J. M. (2014). Potentiating maternal immune tolerance in
2183 pregnancy: a new challenging role for regulatory T cells. *Placenta*, **35**, 241–248.
- 2184 Amoroso, E. C. (1968). The Evolution of Viviparity. *Proceedings of the Royal Society of*
2185 *Medicine* **61**.
- 2186 Ander, S. E., M. S. Diamond, and C. B. Coyne. (2019). Immune Responses at the Maternal-Fetal
2187 Interface. *Science Immunology* **4**(31).
- 2188 Anderson, R. E., C. V. Gay, and H. Schraer. (1981). Ultrastructural Localization of Carbonic
2189 Anhydrase in the Chorioallantoic Membrane by Immunocytochemistry. *Journal of*
2190 *Histochemistry and Cytochemistry* **29**(10), 1121–27.
- 2191 Anderson, D. J., N. C. Stoyan, and R. E. Ricklefs. (1987). Why Are There No Viviparous Birds?
2192 A Comment. *The American Naturalist* **130**(6), 941–47.

- 2193 Andrukhova, O., C. Streicher, U. Zeitz, and R. G. Erben. (2016). Molecular and Cellular
2194 Endocrinology FGF23 and Parathyroid Hormone Signaling Interact in Kidney and Bone.
2195 *Molecular and Cellular Endocrinology* **436**, 224–39.
- 2196 Aoki, R. (1993). The multiple origins of the eggshell in amniote evolution. *Journal of Fossil*
2197 *Research* **27**, 9–43.
- 2198 Arazi, H., I. Yoselewitz, Y. Malka, Y. Kelner, O. Genin, and M. Pines. (2009). Osteopontin and
2199 Calbindin Gene Expression in the Eggshell Gland as Related to Eggshell Abnormalities.
2200 *Poultry Science* **88**(3), 647–53.
- 2201 Arcellana-Panlilio, M. Y., and G. A. Schultz. (1994). Temporal and Spatial Expression of Major
2202 Histocompatibility Complex Class I H-2K in the Early Mouse Embryo. *Biology of*
2203 *Reproduction* **51**(2), 169–83.
- 2204 Arck, P. C., and K. Hecher. (2013). Fetomaternal Immune Cross-Talk and Its Consequences for
2205 Maternal and Offspring’s Health. *Nature Medicine* **19**(5), 548–56.
- 2206 Arenas-Hernandez, M., R. Romero, D. St Louis, S. S. Hassan, E. B. Kaye, and N. Gomez-Lopez.
2207 (2016). An Imbalance between Innate and Adaptive Immune Cells at the Maternal-Fetal
2208 Interface Occurs Prior to Endotoxin-Induced Preterm Birth. *Cellular and Molecular*
2209 *Immunology* **13**(4), 462–73.
- 2210 Arias, J. L., M. Cataldo, M. S. Fernandez, and E. Kessi. (1997). Effect of Beta-
2211 aminopropionitrile on Eggshell Formation. *British Poultry Science* **38**(4), 349–54.

- 2212 Arias, J. L., D. J. Fink, S. Qun Xiao, A. H. Heuer, and A. I. Caplan. (1993). Biomineralization
2213 and Eggshells: Cell-Mediated Acellular Compartments of Mineralized Extracellular
2214 Matrix. *International Review of Cytology* **145**(C), 217–50.
- 2215 Arrowsmith, S., and S. Wray. (2014). Oxytocin: Its Mechanism of Action and Receptor
2216 Signaling in the Myometrium. *Journal of Neuroendocrinology* **26**(6), 356–69.
- 2217 Astheimer, L., and C. R. Grau. (1990). A Comparison of Yolk Growth Rates in Seabird Eggs.
2218 *Ibis* **132**(3), 380–94.
- 2219 Atikuzzaman, M., M. Alvarez-Rodriguez, A. V. Carrillo, M. Johnsson, D. Wright, and H.
2220 Rodriguez-Martinez. (2017). Conserved Gene Expression in Sperm Reservoirs between
2221 Birds and Mammals in Response to Mating. *BMC Genomics* **18**(1).
- 2222 Atikuzzaman, M., R. M. Bhai, J. Fogelholm, D. Wright, and H. Rodriguez-Martinez. (2015).
2223 Mating Induces the Expression of Immune- and PH-Regulatory Genes in the Utero-
2224 Vaginal Junction Containing Mucosal Sperm-Storage Tubuli of Hens. *Reproduction*
2225 **150**(6), 473–83.
- 2226 Attias, M., T. Al-Aubodah, and C. A. Piccirillo. (2019). Mechanisms of Human FoxP3+ Treg
2227 Cell Development and Function in Health and Disease. *Clinical and Experimental*
2228 *Immunology* **197**(1), 36–51.
- 2229 Axiak-Bechtel, S. M., S. R. Kumar, S. A. Hansen, and J. N. Bryan. (2013). Y-Chromosome
2230 DNA Is Present in the Blood of Female Dogs Suggesting the Presence of Fetal
2231 Microchimerism. *PLoS ONE* **8**(7), 1–6.

- 2232 Baardman, M. E., W. S. Kerstjens-Frederikse, R. M. F. Berger, M. K. Bakker, R. M. W. Hofstra,
2233 and T. Plösch. (2013). The Role of Maternal-Fetal Cholesterol Transport in Early Fetal
2234 Life: Current Insights. *Biology of Reproduction* **88**(1), 1–9.
- 2235 Bakker, R., S. Pierce, and D. Myers. (2017). The Role of Prostaglandins E1 and E2,
2236 Dinoprostone, and Misoprostol in Cervical Ripening and the Induction of Labor: A
2237 Mechanistic Approach. *Archives of Gynecology and Obstetrics* **296**(2), 167–79.
- 2238 Bakkour, S., C. A. R. Baker, A. F. Tarantal, L. Wen, M. P. Busch, T. H. Lee, and J. M. McCune.
2239 (2014). Analysis of Maternal Microchimerism in Rhesus Monkeys (*Macaca Mulatta*)
2240 Using Real-Time Quantitative PCR Amplification of MHC Polymorphisms. *Chimerism*
2241 **5**(1), 6–15.
- 2242 Balogh, A., E. Toth, R. Romero, K. Parej, D. Csala, N. L. Szenasi, I. Hajdu, K. Juhasz, A. F.
2243 Kovacs, and H. Meiri. (2019). Placental Galectins Are Key Players in Regulating the
2244 Maternal Adaptive Immune Response. *Frontiers in Immunology* **10**.
- 2245 Bar, A., (2009a). Calcium Transport in Strongly Calcifying Laying Birds: Mechanisms and
2246 Regulation. *Comparative Biochemistry and Physiology - A Molecular and Integrative*
2247 *Physiology* **152**(4), 447–69.
- 2248 ———. (2009b). Differential Regulation of Calbindin in the Calcium-Transporting Organs of
2249 Birds with High Calcium Requirements. *The Journal of Poultry Science* **46**(4), 267–85.
- 2250 Bar, A., J. Rosenberg, and S. Hurwitz. (1984). The Lack of Relationships between Vitamin D3
2251 Metabolites and Calcium-Binding Protein in the Eggshell Gland of Laying Birds.
2252 *Comparative Biochemistry and Physiology -- Part B* **78**(1), 75–79.

- 2253 Baratelli, F., Y. Lin, L. Zhu, Seok-Chul Yang, N. Heuzé-Vourc'h, G. Zeng, K. Reckamp, M.
2254 Dohadwala, S. Sharma, and S. M. Dubinett. (2005). Prostaglandin E₂ Induces FOXP3
2255 Gene Expression and T Regulatory Cell Function in Human CD4⁺ T Cells. *The Journal*
2256 *of Immunology* **175**(3), 1483–90.
- 2257 Bardet, C., S. Delgado, and J.Y. Sire. (2010a). MEPE evolution in mammals reveals regions and
2258 residues of prime functional importance. *Cellular and Molecular Life Sciences* **67**, 305–320.
- 2259 Bardet, C., C. Vincent, M.C. Lajarille, T. Jaffredo, and J.Y. Sire, (2010b). OC-116, the chicken
2260 ortholog of mammalian MEPE found in eggshell, is also expressed in bone cells. *Journal of*
2261 *Experimental Zoology Part B: Molecular and Developmental Evolution* **314**, 653–662.
- 2262 Barua, A., and Y. Yoshimura. (1999). Effects of Aging and Sex Steroids on the Localization of T
2263 Cell Subsets in the Ovary of Chicken, Gallus Domesticus. *General and Comparative*
2264 *Endocrinology* **114**(1), 28–35.
- 2265 Bayes-Genis, A., B. Bellosillo, O. De La Calle, M. Salido, S. Roura, F. Solé Ristol, C. Soler, et
2266 al. (2005). Identification of Male Cardiomyocytes of Extracardiac Origin in the Hearts of
2267 Women with Male Progeny: Male Fetal Cell Microchimerism of the Heart. *Journal of*
2268 *Heart and Lung Transplantation* **24**(12), 2179–83.
- 2269 Bazer, F. W. (1975). Uterine Protein Secretions: Relationship to Development of the Conceptus.
2270 *Journal of Animal Science* **41**(5), 1376–82.
- 2271 ———. (1992). Mediators of Maternal Recognition of Pregnancy in Mammals. *Proceedings of*
2272 *the Society for Experimental Biology and Medicine* **199**(4), 373–84.

- 2273 Bazer, F. W. (2013). Pregnancy Recognition Signaling Mechanisms in Ruminants and Pigs.
2274 *Journal of Animal Science and Biotechnology* **4**(1),1–10.
- 2275 Bazer, F. W, T. E. Spencer, and T. L. Ott. (1997). Interferon Tau: A Novel Pregnancy
2276 Recognition Signal. *American Journal of Reproductive Immunology* **37**(6), 412–20.
- 2277 Bazer, F. W., G. Wu, G. A. Johnson, J. Kim, and G. Song. (2011). Uterine Histotroph and
2278 Conceptus Development: Select Nutrients and Secreted Phosphoprotein 1 Affect
2279 Mechanistic Target of Rapamycin Cell Signaling in Ewes. *Biology of Reproduction*
2280 **85**(6), 1094–1107.
- 2281 Behrman, H. R., T. Endo, R. F. Aten, and B. Musicki. (1993). Corpus Luteum Function and
2282 Regression. *Reproductive Medicine Review* **2**(3), 153–80.
- 2283 Belkacemi, L., I. Bédard, L. Simoneau, and J. Lafond. (2005). Calcium Channels, Transporters
2284 and Exchangers in Placenta: A Review. *Cell Calcium* **37**(1), 1–8.
- 2285 Belkacemi, L., G. Gariépy, C. Mounier, L. Simoneau, and J. Lafond. (2004). Calbindin-D9k
2286 (CaBP9k) Localization and Levels of Expression in Trophoblast Cells from Human Term
2287 Placenta. *Cell and Tissue Research* **315**(1), 107–17.
- 2288 Belkacemi, L., L. Simoneau, and J. Lafond. (2002). Calcium-Binding Proteins. *Endocrine* **19**(1),
2289 57–64.
- 2290 Benedictusa, L., A. P. Koets, and V. P. M. G. Ruttena. (2015). The Role of Placental MHC Class
2291 I Expression in Immune Assisted Separation of the Fetal Membranes in Cattle. *Journal of*
2292 *Reproductive Immunology* **112**, 11–19.

- 2293 Bianchi, D. W., G. K. Zickwolf, G. J. Weil, S. Sylvester, and M. A. Demaria. (1996). Male Fetal
2294 Progenitor Cells Persist in Maternal Blood for as Long as 27 Years Postpartum.
2295 *Proceedings of the National Academy of Sciences* **93**(2), 705–8.
- 2296 Biazik, J. M., S. L. Parker, C. R. Murphy, and M. B. Thompson. (2012). Uterine Epithelial
2297 Morphology and Progesterone Receptors in a Mifepristone-treated Viviparous Lizard
2298 *Pseudemoia entrecasteauxii* (Squamata: Scincidae) During Gestation. *Journal of*
2299 *Experimental Zoology* **318**(2), 148–58.
- 2300 Biber, J., N. Hernando, and I. Forster. (2013). Phosphate Transporters and Their Function.
2301 *Annual Review of Physiology* **75**(1), 535–50.
- 2302 Billingham, R. E., L. Brent, and P. B. Medawar. (1953). ‘Actively Acquired Tolerance’ of
2303 Foreign Cells. *Nature* **172**(4379), 603–6.
- 2304 Bindels, R. J. (1993). Calcium Handling by the Mammalian Kidney. *The Journal of*
2305 *Experimental Biology* **184**, 89–104.
- 2306 Blackburn, D. G. (1982). Evolutionary Origins of Viviparity in the Reptilia. I. Sauria. *Amphibia-*
2307 *Reptilia* **3**(2), 185–205.
- 2308 Blackburn, D. G. (1999). Viviparity and Oviparity - Evolution and Strategies. *Encyclopedia of*
2309 *Reproduction* **4**(May), 994–1003.
- 2310 ———. (1985). Evolutionary Origins of Viviparity in the Reptilia. II. Serpentes, Amphisbaenia,
2311 and Ichthyosauria. *Amphibia Reptilia* **6**(3), 259–91.

- 2312 ———. (1992). Convergent Evolution of Viviparity, Matrotrophy, and Specializations for Fetal
2313 Nutrition in Reptiles and Other Vertebrates. *Integrative and Comparative Biology* **32**(2),
2314 313–21.
- 2315 ———. (1993). Chorioallantoic Placentation in Squamate Reptiles: Structure, Function,
2316 Development, and Evolution. *Journal of Experimental Zoology* **266**(5), 414–30.
- 2317 ———. (1995). Saltationist and Punctuated Equilibrium Models for the Evolution of Viviparity
2318 and Placentation. *Journal of Theoretical Biology* **174**(2), 199–216.
- 2319 ———. (1998). Structure, Function, and Evolution of the Oviducts of Squamate Reptiles, With
2320 Special Reference to Viviparity and Placentation. *The Journal of Experimental Zoology*
2321 **282**, 560–617.
- 2322 ———. (1999). Are Viviparity and Egg-Guarding Evolutionarily Labile in Squamates?
2323 *Herpetologica* **55**(4), 556–73.
- 2324 ———. (2000). Reptilian Viviparity: Past Research, Future Directions, and Appropriate Models.
2325 *Comparative Biochemistry and Physiology - A Molecular and Integrative Physiology*
2326 **127**(4), 391–409.
- 2327 ———. (2005). Amniote Perspectives on the Evolutionary Origins of Viviparity and
2328 Placentation. *Viviparity in Fishes* **319**, 40.
- 2329 ———. (2006). Squamate Reptiles as Model Organisms for the Evolution of Viviparity.
2330 *Herpetological Monographs* **20**(1), 131.

- 2331 ———. (2015a). Evolution of Vertebrate Viviparity and Specializations for Fetal Nutrition: A
2332 Quantitative and Qualitative Analysis. *Journal of Morphology* **276**(8), 961–90.
- 2333 ———. (2015b). Viviparous Placentotrophy in Reptiles and the Parent-Offspring Conflict.
2334 *Journal of Experimental Zoology* **324**(6), 532–48.
- 2335 ———. (2021). Functional Morphology, Diversity, and Evolution of Yolk Processing
2336 Specializations in Embryonic Reptiles and Birds. *Journal of Morphology* **282**(7), 995–
2337 1014.
- 2338 Blackburn, D. G., and A. F. Flemming. (2012). Invasive Implantation and Intimate Placental
2339 Associations in a Placentotrophic African Lizard, *Trachylepis Ivensi* (Scincidae). *Journal*
2340 *of Morphology* **273**(2), 137–59.
- 2341 Blackburn, D. G., L. Lestz, M. S. Barnes, and K. G. Powers. (2019). How Do Embryonic Turtles
2342 Process Yolk? Evidence from the Snapping Turtle, *Chelydra Serpentina* (Chelydridae).
2343 *Canadian Journal of Zoology* **97**(6), 495–501.
- 2344 Blackburn, D. G., and R. L. Lorenz. (2003). Placentation in Garter Snakes. II. Transmission EM
2345 of the Chorioallantoic Placenta of *Thamnophis Radix* and *T. Sirtalis*. *Journal of*
2346 *Morphology* **256**(2), 171–86.
- 2347 Blackburn, D. G., and L. J. Vitt. (2002). Specializations of the Chorioallantoic Placenta in the
2348 Brazilian Scincid Lizard, *Mabuya heathi*: A New Placental Morphotype for Reptiles.
2349 *Journal of Morphology* **254**(2), 121–31.

- 2350 Blackburn, D. G., and J. R. Stewart. (2021). Morphological research on amniote eggs and
2351 embryos: An introduction and historical retrospective. *Journal of Morphology* **282**(7),
2352 1024–1046
- 2353 Blaine, J., M. Chonchol, and M. Levi. (2015). Renal Control of Calcium, Phosphate, and
2354 Magnesium Homeostasis. *Clinical Journal of the American Society of Nephrology* **10**(7),
2355 1257–72.
- 2356 Blomberg, L. A., L. L. Schreier, H. David Guthrie, G. L. Sample, J. Vallet, T. Caperna, and T.
2357 Ramsay. (2010). The Effect of Intrauterine Growth Retardation on the Expression of
2358 Developmental Factors in Porcine Placenta Subsequent to the Initiation of Placentation.
2359 *Placenta* **31**(6), 549–52.
- 2360 Boehm, T., M. Hirano, S. J. Holland, S. Das, M. Schorpp, and M. D. Cooper. (2018). Evolution
2361 of Alternative Adaptive Immune Systems in Vertebrates. *Annual Review of Immunology*
2362 **36**, 19–42.
- 2363 Bonnet, X., G. Naulleau, D. Bradshaw, and R. Shine. (2001). Changes in Plasma Progesterone in
2364 Relation to Vitellogenesis and Gestation in the Viviparous Snake *Vipera aspis*. *General*
2365 *and Comparative Endocrinology* **121**(1), 84–94.
- 2366 Bonnet, X., G. Naulleau, and R. Shine. (2017). The Evolutionary Economics of Embryonic-Sac
2367 Fluids in Squamate Reptiles. *American Naturalist* **189**(3), 333–44.
- 2368 Borgnia, M., S. Nielsen, A. Engel, and P. Agre. (1999). Cellular and Molecular Biology of the
2369 Aquaporin Water Channels. *Annual Reviews in Biochemistry*. **68**, 425–58.

- 2370 Borziak, K., A. Álvarez-Fernández, T. L. Karr, T. Pizzari, and S. Dorus. (2016). The Seminal
2371 Fluid Proteome of the Polyandrous Red Junglefowl Offers Insights into the Molecular
2372 Basis of Fertility, Reproductive Ageing and Domestication. *Scientific Reports* **6**, 1–15.
- 2373 Boyson, J. E., K. K. Iwanaga, T. G. Golos, and D. I. Watkins. (1997). Identification of a Novel
2374 MHC Class I Gene, Mamu-AG, Expressed in the Placenta of a Primate with an
2375 Inactivated G Locus. *Journal of Immunology (Baltimore, Md: 1950)* **159**(7), 3311–21.
- 2376 Brace, R. A. (1997). Physiology of Amniotic Fluid Volume Regulation. *Clinical Obstetrics and*
2377 *Gynecology* **40**(2), 280–89.
- 2378 Brandley, M. C., R. L. Young, D. L. Warren, M. B. Thompson, and G. P. Wagner. (2012).
2379 Uterine Gene Expression in the Live-Bearing Lizard, *Chalcides Ocellatus*, Reveals
2380 Convergence of Squamate Reptile and Mammalian Pregnancy Mechanisms. *Genome*
2381 *Biology and Evolution* **4**(3), 394–411.
- 2382 Brawand, D., W. Wahli, and H. Kaessmann. (2008). Loss of Egg Yolk Genes in Mammals and
2383 the Origin of Lactation and Placentation. *PLoS Biology* **6**(3), 0507–17.
- 2384 Braz, H. B., R.R. Scartozzoni, and S.M. Almeida-Santos, S. M. (2016). Reproductive modes of
2385 the South American water snakes: A study system for the evolution of viviparity in
2386 squamate reptiles. *Zoologischer Anzeiger* **263**, 33-44.
- 2387 Braz, H. B., S. M. Almeida-Santos, C. R. Murphy, and M. B. Thompson. (2018). Uterine and
2388 Eggshell Modifications Associated with the Evolution of Viviparity in South American
2389 Water Snakes (*Helicops* spp.). *Journal of Experimental Zoology* **330**(3), 165–80.

2390 Brennan, S. C., U. Thiem, S. Roth, A. Aggarwal, I. S. Fetahu, S. Tennakoon, A. R. Gomes, et al.
2391 (2013). Calcium Sensing Receptor Signaling in Physiology and Cancer. *Biochimica et*
2392 *Biophysica Acta - Molecular Cell Research* **1833**(7), 1732–44.

2393 Breuss, J. M., N. Gillett, L. Lu, D. Sheppard, and R. Pytela. (1993). Restricted Distribution of
2394 Integrin B6 mRNA in Primate Epithelial Tissues. *Journal of Histochemistry and*
2395 *Cytochemistry* **41**(10), 1521–27.

2396 Brionne, A., Y. Nys, C. Hennequet-Antier, and J. Gautron. (2014). Hen Uterine Gene Expression
2397 Profiling during Eggshell Formation Reveals Putative Proteins Involved in the Supply of
2398 Minerals or in the Shell Mineralization Process. *BMC Genomics* **15**(202), 1–18.

2399 Bronner, F. (2003). Mechanisms of Intestinal Calcium Absorption. In *Journal of Cellular*
2400 *Biochemistry*. **88**, 387–93.

2401 Bulmer, J. N., L. Morrison, M. Longfellow, A. Ritson, and De. Pace. (1991). Granulated
2402 Lymphocytes in Human Endometrium: Histochemical and Immunohistochemical
2403 Studies. *Human Reproduction* **6**(6), 791–98.

2404 Bulmer, J. N., P. J. Williams, and G. E. Lash. (2010). Immune Cells in the Placental Bed.
2405 *International Journal of Developmental Biology* **54**(2–3), 281–94.

2406 Burbrink, F. T., F. G. Grazziotin, A. Pyron, D. Cundall, S. Donnellan, F. Irish, J. S. Keogh, F.
2407 Kraus, R. W. Murphy, B. Noonan, C. J. Raxworthy, S. Ruane, A. R. Lemmon, E.
2408 Moriarty Lemmon, H. Zaher. (2020). Interrogating Genomic-Scale Data for Squamata
2409 (Lizards, Snakes, and Amphisbaenians) Shows No Support for Key Traditional
2410 Morphological Relationships. *Systematic Biology* **69**(3), 502–20.

2411 Burlingham, W., and W. Bracamonte-Baran (2015). Non-Inherited Maternal Antigens,
2412 Pregnancy, and Allotolerance. *Biomedical Journal* **38**(1), 39–51.

2413 Burlingham, W. (2010). Chimerism, Tolerance, and Twins. *Obstetrics & Gynecology* **116**(2),
2414 475–76.

2415 Burton, F. G., and S. G. Tullett. (1985). Respiration of Avian Embryos. *Comparative*
2416 *Biochemistry and Physiology -- Part A: Physiology* **82**(4), 735–44.

2417 Burton, G. J., A. L. Watson, J. Hempstock, J. N. Skepper, and E. Jauniaux. (2002). Uterine
2418 Glands Provide Histiotrophic Nutrition for the Human Fetus during the First Trimester of
2419 Pregnancy. *Journal of Clinical Endocrinology and Metabolism* **87**(6), 2954–59.

2420 Cadet, P., P. L. Rady, S. K. Tying, R. B. Yandell, and T. K. Hughes. (1995). Interleukin-10
2421 Messenger Ribonucleic Acid in Human Placenta: Implications of a Role for Interleukin-
2422 10 in Fetal Allograft Protection. *American Journal of Obstetrics and Gynecology* **173**(1),
2423 25–29.

2424 Callard, I. P., L. A. Fileti, L. E. Perez, L. A. Sorbera, L. L. Klosterman, P. Tsang, J. A.
2425 Mccracken, et al. (1992). Role of the Corpus Luteum and Progesterone in the Evolution
2426 of Vertebrate Viviparity. *Integrative and Comparative Biology* **32**(2), 264–75.

2427 Camaiti, M., Evans, A.R., Hipsley, C.A. and Chapple, D.G. (2021), A farewell to arms and legs:
2428 a review of limb reduction in squamates. *Biological Reviews* **96**, 1035-1050.

2429 Canalis E., Economides A.N., Gazzero E. (2003). Bone Morphogenetic Proteins, their
2430 Antagonists, and the Skeleton *Endocr Rev.* **24**(2), 218–35.

- 2431 Caniggia, I., H. Mostachfi, J. Winter, M. Gassmann, S. J. Lye, M. Kuliszewski, and M. Post.
2432 (2000). Hypoxia-Inducible Factor-1 Mediates the Biological Effects of Oxygen on
2433 Human Trophoblast Differentiation through TGF β 3. *Journal of Clinical Investigation*
2434 **105**(5), 577–87.
- 2435 Capecchi, E., Lobo, J.L., I., Laña, J. I. Espinosa-Ramos, and N. Kasabov. (2020). Modelling gene
2436 interaction networks from time-series gene expression data using evolving spiking neural
2437 networks. *Evolving Systems* **11**, 599–613.
- 2438 Carosella, E. D., N. Rouas-Freiss, D. Tronik-Le Roux, P. Moreau, and J. LeMaoult. (2015).
2439 HLA-G: An Immune Checkpoint Molecule. *Advances in Immunology* **127**, 33–144.
- 2440 Carter, A. M. (2009). Evolution of Factors Affecting Placental Oxygen Transfer. *Placenta* **30**,
2441 19–25.
- 2442 Carter, A. M. (2012). Evolution of Placental Function in Mammals: The Molecular Basis of Gas
2443 and Nutrient Transfer, Hormone Secretion, and Immune Responses. *Physiological*
2444 *Reviews* **92**(4), 1543–76.
- 2445 Casey, M. L., and P. C. MacDonald. (1997). The Endocrinology of Human Parturition. *Annals of*
2446 *the New York Academy of Sciences* **828**, 273–84.
- 2447 Castracane, V. D., and J. W. Goldzieher. (1986). Timing of the Luteal-Placental Shift in the
2448 Baboon (*Papio Cynocephalus*). *Endocrinology* **118**(2), 506–12.
- 2449 Caterson B, J. Melrose (2018). Keratan sulfate, a complex glycosaminoglycan with unique
2450 functional capability. *Glycobiology* **28**(4), 182-206.

- 2451 Challis, J. R. G., F. H. Bloomfield, A. D. Bocking, V. Casciani, H. Chisaka, K. Connor, X.
2452 Dong, P. Gluckman, J. E. Harding, and J. Johnstone. (2005). Fetal Signals and
2453 Parturition. *Journal of Obstetrics and Gynaecology Research* **31**(6), 492–99.
- 2454 Challis, J. R., C. J. Lockwood, L. Myatt, J. E. Norman, J. F. Strauss, and F. Petraglia. (2009).
2455 Inflammation and Pregnancy. *Reproductive Sciences* **16**(2), 206–15.
- 2456 Challis, J. R. G., S. G. Matthews, W. Gibb, and S. J. Lye. (2000). Endocrine and Paracrine
2457 Regulation of Birth at Term and Preterm. *Endocrine Reviews* **21**(5), 514–50.
- 2458 Chamberlain, P. F., F. A. Manning, I. Morrison, C. R. Harman, and I. R. Lange. (1984).
2459 Ultrasound Evaluation of Amniotic Fluid Volume: I. The Relationship of Marginal and
2460 Decreased Amniotic Fluid Volumes to Perinatal Outcome. *American Journal of*
2461 *Obstetrics and Gynecology* **150**(3), 245–49.
- 2462 Chaouat, G. (2016). Reconsidering the Medawar Paradigm Placental Viviparity Existed for
2463 Eons, Even in Vertebrates; without a ‘Problem’: Why Are Tregs Important for
2464 Preeclampsia in Great Apes ? *Journal of Reproductive Immunology* **114**, 48–57.
- 2465 Chaouat, G., J. Tranchot Diallo, J. L. Volumenie, E. Menu, G. Gras, G. Delage, and B. Mognetti.
2466 (1997). Immune Suppression and Th1/Th2 Balance in Pregnancy Revisited: A (Very)
2467 Personal Tribute to Tom Wegmann. *American Journal of Reproductive Immunology*
2468 **37**(6), 427–34.
- 2469 Chaouat, G., M. Petitbarat, S. Dubanchet, M. Rahmati, and N. Ledée. (2010). Tolerance to the
2470 Foetal Allograft? *American Journal of Reproductive Immunology* **63**(6), 624–36.

- 2471 Charpigny, G., M. J. Leroy, M. Breuiller-Fouché, Z. Tanfin, S. Mhaouty-Kodja, P. Robin, D.
2472 Leiber, et al. (2003). A Functional Genomic Study to Identify Differential Gene
2473 Expression in the Preterm and Term Human Myometrium. *Biology of Reproduction*
2474 **68**(6), 2289–96.
- 2475 Chatterjee-Hasrouni, S., and P. K. Lala. (1982). On Murine of Paternal Trophoblast H-2K
2476 Antigens Cells in Vivo. *Journal of Experimental Medicine* **155**(6), 1679–89.
- 2477 Chattopadhyay, A., N. Robinson, J. K. Sandhu, B. B. Finlay, S. Sad, and L. Krishnan. (2010).
2478 Salmonella Enterica Serovar Typhimurium-Induced Placental Inflammation and Not
2479 Bacterial Burden Correlates with Pathology and Fatal Maternal Disease. *Infection and*
2480 *Immunity* **78**(5), 2292–2301.
- 2481 Chaturvedi, V., J. M. Ertelt, T. T. Jiang, J. M. Kinder, L. Xin, K. J. Owens, H. N. Jones, and S.
2482 S. Way. (2015). CXCR3 Blockade Protects against *Listeria Monocytogenes* Infection-
2483 Induced Fetal Wastage. *Journal of Clinical Investigation* **125**(4), 1713–25.
- 2484 Chavan, A. R., O. W. Griffith, and G. P. Wagner. (2017). The Inflammation Paradox in the
2485 Evolution of Mammalian Pregnancy: Turning a Foe into a Friend. *Current Opinion in*
2486 *Genetics and Development* **47**, 24–32.
- 2487 Chen, L., C. Chu, X. Kong, G. Huang, T. Huang, and Y. Dong Cai. (2015). A Hybrid
2488 Computational Method for the Discovery of Novel Reproduction-Related Genes. *PLoS*
2489 *ONE* **10**(3), 1–15.
- 2490 Chien, Y. C., M. T. Hincke, and M. D. McKee. (2008). Avian Eggshell Structure and
2491 Osteopontin. *Cells Tissues Organs* **189**(1–4), 38–43.

- 2492 ———. (2009). Ultrastructure of Avian Eggshell during Resorption Following Egg Fertilization.
2493 *Journal of Structural Biology* **168**(3): 527–38.
- 2494 Chmurzyńska, A., (2006). The Multigene Family of Fatty Acid-Binding Proteins (FABPs):
2495 Function, Structure and Polymorphism. *Journal of Applied Genetics* **47**(1), 39–48.
- 2496 Choi, S., S. Han, N. H. Kim, Y. N. Lee. (2018). A Comparative Study of Eggshells of Gekkota
2497 with Morphological, Chemical Compositional and Crystallographic Approaches and its
2498 Evolutionary Implications. *PLOS ONE*. **13**(6), e0199496
- 2499 Seung Choi, N.-H. Kim, H.-I Kim, J.J. Kweon, S.K. Lee, S. Zhang, D.J. Varricchio. (2022)
2500 Preservation of aragonite in Late Cretaceous (Campanian) turtle eggshell
2501 *Palaeogeography, Palaeoclimatology, Palaeoecology* **585**, 110741.
- 2502 Chowdhury, S. D., and R. H. Davis. (1995). Influence of Dietary Osteolathyrogens on the
2503 Ultrastructure of Shell and Membranes of Eggs from Laying Hens. *British Poultry*
2504 *Science* **36**(4), 575–83.
- 2505 Christiaens, I., D. B. Zaragoza, L. Guilbert, S. A. Robertson, B. F. Mitchell, and D. M. Olson.
2506 (2008). Inflammatory Processes in Preterm and Term Parturition. *Journal of*
2507 *Reproductive Immunology* **79**(1), 50–57.
- 2508 Chu, T. M., and E. Kawinski. (1998). Plasmin, Subtilisin-like Endoproteases, Tissue
2509 Plasminogen Activator, and Urokinase Plasminogen Activator Are Involved in Activation
2510 of Latent TGF- β 1 in Human Seminal Plasma. *Biochemical and Biophysical Research*
2511 *Communications* **253**(1), 128–34.

- 2512 Chuliver, M., Scanferla A., Smith K. T. (2022). Live birth in a 47-million-year-old snake. *The*
2513 *Science of Nature* **109**(6), 56.
- 2514 Cindrova-Davies, T., E. Jauniaux, M. G. Elliot, S. Gong, G. J. Burton, and D. S. Charnock-
2515 Jones. (2017). RNA-Seq Reveals Conservation of Function among the Yolk Sacs of
2516 Human, Mouse, and Chicken. *Proceedings of the National Academy of Sciences* 114(24),
2517 E4753–61.
- 2518 Coleman, J. R., and A. R. Terepka. (1972). Electron Probe Analysis of the Calcium Distribution
2519 in Cells of the Embryonic Chick Chorioallantoic Membrane. I. A Critical Evaluation of
2520 Techniques. *The Journal of Histochemistry and Cytochemistry* **20**(6), 401–13.
- 2521 Cooke, P. S., T. E. Spencer, F. F. Bartol, and K. Hayashi. (2013). Uterine Glands: Development,
2522 Function and Experimental Model Systems. *Molecular Human Reproduction* **19**(9),
2523 547–58.
- 2524 **Cornelis, G., Funk, M., Vernochet, C., Leal, F., Tarazona, O. A.,** Meurice, G., ... &
2525 Heidmann, T. (2017). An endogenous retroviral envelope syncytin and its cognate
2526 receptor identified in the viviparous placental Mabuya lizard. *Proceedings of the National*
2527 *Academy of Sciences* **114**(51), E10991-E11000.
- 2528 Cornetti, L., O. W. Griffith, A. Benazzo, A. Panziera, C. M. Whittington, M. B. Thompson, C.
2529 Vernesi, and G. Bertorelle. (2018). Candidate Genes Involved in the Evolution of
2530 Viviparity: A RAD Sequencing Experiment in the Lizard *Zootoca vivipara* (Squamata:
2531 Lacertidae). *Zoological Journal of the Linnean Society* **183**(1), 196–207.

- 2532 Corso, G., G. M. Delitala, and M. Carcupino. (2000). Uterine Morphology during the Annual
2533 Cycle in *Chalcides ocellatus tiligugu* (Squamata: Scincidae). *Journal of Morphology*
2534 **243**(2), 153–65.
- 2535 Corso, G., M. Pala, A. M. Pinna, and M. Carcupino. (1988). Aspetti Morfofunzionali
2536 Dell’ovidutto Di *Chalcides Ocellatus Tiligugu* (Squamata, Scincidae). *Italian*
2537 *Journal of Anatomy and Embryology* **93**(4), 237–51.
- 2538 Cox, C. L., R. T. Peaden, and R. M. Cox. (2015). The Metabolic Cost of Mounting an Immune
2539 Response in Male Brown Anoles (*Anolis sagrei*). *Journal of Experimental Zoology*
2540 **323**(10), 689–95.
- 2541 Cree, A., and L. J. Guillette. (1991). Effect Of-Adrenergic Stimulation on Uterine Contraction in
2542 Response to Arginine Vasotocin and Prostaglandin F2a in the Gecko *Hoplodactylus*
2543 *maculatus*. *Biology of Reproduction*. **44**
- 2544 Cuellar, H. S. (1979). Disruption of Gestation and Egg Shelling in Deluteinized Oviparous
2545 Whiptail Lizards *Cnemidophorus uniparens* (Reptilia: Teiidae). *General and*
2546 *Comparative Endocrinology* **39**(2), 150–57.
- 2547 Custodia-Lora, N., A. Novillo, and I. P. Callard. (2004). Regulation of Hepatic Progesterone and
2548 Estrogen Receptors in the Female Turtle, *Chrysemys Picta*: Relationship to
2549 Vitellogenesis. *General and Comparative Endocrinology* **136**(2), 232–40.
- 2550 Damiano, A. E. 2011. Review: Water Channel Proteins in the Human Placenta and Fetal
2551 Membranes. *Placenta* **32**, S207–11.

- 2552 Das, S. C., N. Isobe, and Y. Yoshimura. (2008). Mechanism of Prolonged Sperm Storage and
2553 Sperm Survivability in Hen Oviduct: A Review. *American Journal of Reproductive*
2554 *Immunology* **60**(6), 477–81.
- 2555 Davies, C. J., J. R. Hill, J. L. Edwards, F. N. Schrick, P. J. Fisher, J. A. Eldridge, and D. H.
2556 Schlafer. (2004). Major Histocompatibility Antigen Expression on the Bovine Placenta:
2557 Its Relationship to Abnormal Pregnancies and Retained Placenta. *Animal Reproduction*
2558 *Science* **82–83**, 267–80.
- 2559 Davies, C. J., J. A. Eldridge, P. J. Fisher, and D. H. Schlafer. (2006). Evidence for Expression of
2560 Both Classical and Non-classical Major Histocompatibility Complex Class I Genes in
2561 Bovine Trophoblast Cells. *American Journal of Reproductive Immunology* **55**(3), 188–
2562 200.
- 2563 de Fraipont, M., J. Clobert, and R. Barbault. (1996). The Evolution of Oviparity with Egg
2564 Guarding and Viviparity in Lizards and Snakes: A Phylogenetic Analysis. *Evolution*
2565 **50**(1), 391–400.
- 2566 De Rensis, F., R. Saleri, P. Tummaruk, M. Techakumphu, and R. N. Kirkwood. (2012).
2567 Prostaglandin F_{2α} and Control of Reproduction in Female Swine: A Review.
2568 *Theriogenology* **77**(1), 1–11.
- 2569 Denison, F. C., A. A. Calder, and R. W. Kelly. (1999). The Action of Prostaglandin E₂ on the
2570 Human Cervix: Stimulation of Interleukin 8 and Inhibition of Secretory Leukocyte
2571 Protease Inhibitor. *American Journal of Obstetrics and Gynecology* **180**(3I), 614–20.

- 2572 Denison, F. C., V. E. Grant, A. A. Calder, and R. W. Kelly. (1999). Seminal Plasma
2573 Components Stimulate Interleukin-8 and Interleukin-10 Release. *Molecular Human*
2574 *Reproduction* **5**(3), 220–26.
- 2575 Denison, F. C., R. W. Kelly, A. A. Calder, and S. C. Riley. (1998). Cytokine Secretion by
2576 Human Fetal Membranes, Decidua and Placenta at Term. *Human Reproduction* **13**(12),
2577 3560–65.
- 2578 Diaz, J. A., A. L. Alonso-Gomez, and M. J. Delgado. (1994). Seasonal Variation of Gonadal
2579 Development, Sexual Steroids, and Lipid Reserves in a Population of the Lizard
2580 *Psammodromus algirus*. *Society for the Study of Amphibia* **28**(2), 199–205.
- 2581 Doty, A., W. C. Buhi, S. Benson, K. E. Scoggin, M. Pozor, M. Macpherson, M. Mutz, and M. H.
2582 T. Troedsson. (2011). Equine CRISP3 Modulates Interaction between Spermatozoa and
2583 Polymorphonuclear Neutrophils. *Biology of Reproduction* **85**(1), 157–64.
- 2584 Druckmann, R., and M. A. Druckmann. (2005). Progesterone and the Immunology of Pregnancy.
2585 *Journal of Steroid Biochemistry and Molecular Biology* **97**(5), 389–96.
- 2586 Duan, C., and J. B. Allard. (2020). Insulin-Like Growth Factor Binding Protein-5 in Physiology
2587 and Disease. *Frontiers in Endocrinology*. **11**.
- 2588 Duncan, W. C. (2000). The Human Corpus Luteum: Remodelling during Luteolysis and
2589 Maternal Recognition of Pregnancy. *Reviews of Reproduction* **5**(1), 12–17.
- 2590 Duncan, W. C., A. S. McNeilly, and P. J. Illingworth. (1998). The Effect of Luteal ‘rescue’
2591 on the Expression and Localization of Matrix Metalloproteinases and Their Tissue

- 2592 Inhibitors in the Human Corpus Luteum. *Journal of Clinical Endocrinology and*
2593 *Metabolism* **83**(7), 2470–78.
- 2594 Durso, A. M., and S. S. French. (2018). Stable Isotope Tracers Reveal a Trade-off between
2595 Reproduction and Immunity in a Reptile with Competing Needs. *Functional Ecology*
2596 **32**(3), 648–56.
- 2597 Ecay, T. W., J. R. Stewart, and D. G. Blackburn. (2004). Expression of Calbindin-D28K by Yolk
2598 Sac and Chorioallantoic Membranes of the Corn Snake, *Elaphe guttata*. *Journal of*
2599 *Experimental Zoology* **302**(6), 517–25.
- 2600 Ecay, T. W., J. R. Stewart, G. Wiessner, and B. Heulin. (2017). Ex Utero Culture of Viviparous
2601 Embryos of the Lizard, *Zootoca vivipara*, Provides Insights into Calcium Homeostasis
2602 during Development. *Comparative Biochemistry and Physiology -Part A: Molecular and*
2603 *Integrative Physiology* **206**, 63–68.
- 2604 Elinson, R. P., and J. R. Stewart. (2014). The Corn Snake Yolk Sac Becomes a Solid Tissue
2605 Filled with Blood Vessels and Yolk-Rich Endodermal Cells. *Biology Letters* **10**(1).
- 2606 Elinson, R. P., J. R. Stewart, L. J. Bonneau, and D. G. Blackburn. (2014). Amniote Yolk Sacs:
2607 Diversity in Reptiles and a Hypothesis on Their Origin. *International Journal of*
2608 *Developmental Biology* **58**(10–12), 889–94.
- 2609 Elliott, C. L. (2001). Nuclear Factor-Kappa B Is Essential for up-Regulation of Interleukin-8
2610 Expression in Human Amnion and Cervical Epithelial Cells. *Molecular Human*
2611 *Reproduction* **7**(8), 787–90.

- 2612 Ellis, M. J., J. H. Livesey, W. J. Inder, T. C. R. Prickett, and R. Reid. (2002). Plasma
2613 Corticotropin-Releasing Hormone and Unconjugated Estriol in Human Pregnancy:
2614 Gestational Patterns and Ability to Predict Preterm Delivery. *American Journal of*
2615 *Obstetrics and Gynecology* **186**(1), 94–99.
- 2616 Emanuel, R. L., B. G. Robinson, E. W. Seely, S. W. Graves, I. Kohane, D. Saltzman, R. Barbieri,
2617 and J. A. Majzoub. (1994). Corticotrophin Releasing Hormone Levels in Human Plasma
2618 and Amniotic Fluid during Gestation. *Clinical Endocrinology* **40**(2), 257–62.
- 2619 Enders, A. C., W. A. Wimsatt, and B. F. King. (1976). Cytological Development of Yolk Sac
2620 Endoderm and Protein-absorptive Mesothelium in the Little Brown Bat, *Myotis*
2621 *lucifugus*. *American Journal of Anatomy* **146**(1), 1–29.
- 2622 Erben, R. G., and O. Andrukhova. (2015). FGF23 Regulation of Renal Tubular Solute Transport.
2623 *Current Opinion in Nephrology and Hypertension* **24**(5), 450–56.
- 2624 Erlebacher, A. (2001). Why Isn't the Fetus Rejected? *Current Opinion in Immunology* **13**(5),
2625 590–93.
- 2626 ———. (2013). Immunology of the Maternal-Fetal Interface. *Annual Review of Immunology* **31**,
2627 387–411.
- 2628 Evans, C. H., T. S. Lee, and A. A. Flugelman. (1995). Spermine-Directed Immunosuppression of
2629 Cervical Carcinoma Cell Sensitivity to a Majority of Lymphokine-Activated Killer
2630 Lymphocyte Cytotoxicity. *Natural Immunity* **14**(3), 157.

- 2631 Evans, P. C., N. Lambert, S. Maloney, D. E. Furst, J. M. Moore, and J. L. Nelson. (1999). Long-
2632 Term Fetal Microchimerism in Peripheral Blood Mononuclear Cell Subsets in Healthy
2633 Women and Women with Scleroderma. *Blood* **93**(6), 2033–37.
- 2634 Ewy, Z. (1970). Effect of Vasotocin and Oxytocin on Oviposition in the Hen. Department of
2635 Physiology, College of Agriculture, **12**, 549-550.
- 2636 Faas, M. M., and P. de Vos. (2017). Uterine NK Cells and Macrophages in Pregnancy. *Placenta*
2637 **56**, 44–52.
- 2638 Faulk, W. P., and J. A. McIntyre. (1983). Immunological Studies of Human Trophoblast:
2639 Markers, Subsets and Functions. *Immunological Reviews* **75**(1), 139–75.
- 2640 Faulk, W. P., and A. Temple. (1976). Distribution of B2 Microglobulin and HLA in Chorionic
2641 Villi of Human Placentae. *Nature* **262** (5571), 799–802.
- 2642 Fazleabas, A. T., J. J. Kim, and Z. Strakova. (2004). Implantation: Embryonic Signals and the
2643 Modulation of the Uterine Environment - A Review. *Placenta* **25**, 26–31.
- 2644 Fazleabas, A. T. (2007). Physiology and Pathology of Implantation in the Human and Nonhuman
2645 Primate. In *Seminars in Reproductive Medicine* **25**, 405–9.
- 2646 Fedakâr, A., S. Semiz, and N. Peker. (2016). Clinical Features of Babies Born to Mothers with
2647 Oligohydramnios: A Two Years' Experience. *Journal of Pregnancy and Child Health*
2648 **3**(2).

- 2649 Fenwick, A. M., H. W. Greene, and C. L. Parkinson. (2011). The Serpent and the Egg:
2650 Unidirectional Evolution of Reproductive Mode in Vipers? *Journal of Zoological*
2651 *Systematics and Evolutionary Research* **50**(1), 59–66.
- 2652 Fergusson, B., and S. D. Bradshaw. (1991). Plasma Arginine Vasotocin, Progesterone, and
2653 Luteal Development during Pregnancy in the Viviparous Lizard *Tiliqua rugosa*. *General*
2654 *and Comparative Endocrinology* **82**(1), 140–51.
- 2655 Fernandez, M. S., M. Araya, and J. L. Arias. (1997). Eggshells Are Shaped by a Precise Spatio-
2656 Temporal Arrangement of Sequentially Deposited Macromolecules. *Matrix Biology*
2657 **16**(1), 13–20.
- 2658 Fernandez, M., A. Moya, L. Lopez, and J. L. Arias. (2001). Secretion Pattern, Ultrastructural
2659 Localization and Function of Extracellular Matrix Molecules Involved in Eggshell
2660 Formation. *Matrix Biology* **19**(8), 793–803.
- 2661 Ferner, K., and A. Mess. (2011). Respiratory Physiology & Neurobiology Evolution and
2662 Development of Fetal Membranes and Placentation in Amniote Vertebrates.
2663 *Respiratory Physiology & Neurobiology* **178**(1), 39–50.
- 2664 Fitch, H S. (1970). Reproductive Cycles in Lizards and Snakes. *University of Kansas Museum of*
2665 *Natural History Miscellaneous Publications* **52**, 1–247.
- 2666 Flemming, A. F., and D. G. Blackburn. (2003). Evolution of Placental Specializations in
2667 Viviparous African and South American Lizards. *Journal of Experimental Zoology Part*
2668 *A: Comparative Experimental Biology* **299**(1), 33–47.

- 2669 Florio, P., L. Cobellis, J. Woodman, F. M. Severi, E. A. Linton, and F. Petraglia. (2002). Levels
2670 of Maternal Plasma Corticotropin-Releasing Factor and Urocortin during Labor. *The*
2671 *Journal of the Society for Gynecologic Investigation* **9**(4), 233–37.
- 2672 Ford, S. P. (1997). Embryonic and Fetal Development in Different Genotypes in Pigs. *Journal of*
2673 *Reproduction and Fertility*. **52**,165–76.
- 2674 Forde, N., M. E. Beltman, G. B. Duffy, P. Duffy, J. P. Mehta, P. Ó’Gaora, J. F. Roche, P.
2675 Lonergan, and M. A. Crowe. (2011). Changes in the Endometrial Transcriptome during
2676 the Bovine Estrous Cycle: Effect of Low Circulating Progesterone and Consequences for
2677 Conceptus Elongation. *Biology of Reproduction* **84**(2), 266–78.
- 2678 Foster, C. S. P., M. B. Thompson, J. U. van Dyke, M. C. Brandley, and C. M. Whittington.
2679 (2020). Emergence of an Evolutionary Innovation: Gene Expression Differences
2680 Associated with the Transition between Oviparity and Viviparity. *Molecular Ecology*
2681 **29**(7), 1315–27.
- 2682 **Foster, C.S.P., J.U. Van Dyke, M.B. Thompson, N.M.A. Smith, C.A. Simpfendorfer, C.R.**
2683 **Murphy, and C.M. Whittington.** (2022) Different Genes are Recruited During
2684 Convergent Evolution of Pregnancy and the Placenta. *Molecular Biology and Evolution*
2685 **39**(4), msac077
- 2686 Fox, S. L, and L. J. Guillette Jr. (1987). Luteal Morphology, Atresia, and Plasma Progesterone
2687 Concentrations during the Reproductive Cycle of Two Oviparous Lizards, *Crotaphytus*
2688 *collaris* and *Eumeces obsoletus*. *American Journal of Anatomy* **179**(4), 324–32.

- 2689 Francesch, A., J. Estany, L. Alfonso, and M. Iglesias. (1997). Genetic Parameters for Egg
2690 Number, Egg Weight, and Eggshell Color in Three Catalan Poultry Breeds. *Poultry*
2691 *Science* **76**(12), 1627–31.
- 2692 Frankenberg, S., and M. B. Renfree. (2018). Conceptus Coats of Marsupials and Monotremes. In
2693 *Current Topics in Developmental Biology* **130**, 357–77.
- 2694 Fregoso, S. P., J. R. Stewart, and T. W. Eday. (2010). Embryonic Mobilization of Calcium in a
2695 Viviparous Reptile: Evidence for a Novel Pattern of Placental Calcium Secretion.
2696 *Comparative Biochemistry and Physiology - A Molecular and Integrative Physiology*
2697 **156**(1), 147–50.
- 2698 French, S. S., G. I. H. Johnston, and M. C. Moore. (2007). Immune Activity Suppresses
2699 Reproduction in Food-Limited Female Tree Lizards *Urosaurus ornatus*. *Functional*
2700 *Ecology* **21**(6), 1115–22.
- 2701 Freyer, C., and M. B. Renfree. (2009). The Mammalian Yolk Sac Placenta. *Journal of*
2702 *Experimental Zoology Part B: Molecular and Developmental Evolution* **312**(6), 545–54.
- 2703 Freyer, C., U. Zeller, and M. B. Renfree. (2003). The Marsupial Placenta: A Phylogenetic
2704 Analysis. *Journal of Experimental Zoology* **299**(1), 59–77.
- 2705 Fujiki, Y., K. L. Johnson, H. Tighiouart, I. Peter, and D. W. Bianchi. (2008). Fetomaternal
2706 Trafficking in the Mouse Increases as Delivery Approaches and Is Highest in the
2707 Maternal Lung. *Biology of Reproduction* **79**(5), 841–48.

- 2708 Funderburgh, J. L. (2002). Keratan sulfate biosynthesis. *International Union of Biochemistry*
2709 *and Molecular Biology Life* **54**(4), 187-94.
- 2710 Gao, H., G. Wu, T. E. Spencer, G. A. Johnson, and F. W. Bazer. (2009). Select Nutrients in the
2711 Ovine Uterine Lumen. IV. Expression of Neutral and Acidic Amino Acid Transporters in
2712 Ovine Uteri and Peri-Implantation Conceptuses1. *Biology of Reproduction* **80**(6), 1196–
2713 1208.
- 2714 Gao, J. F., Y. F. Qu, L. G. Luo, and X. Ji. (2010). Evolution of Reptilian Viviparity: A Test of the
2715 Maternal Manipulation Hypothesis in a Temperate Snake, *Gloydius brevicaudus*
2716 (*Viperidae*). *Zoological Science* **27**(3), 248–55.
- 2717 Gao, W., Y. B. Sun, W. W. Zhou, Z. J. Xiong, L. Chen, H. Li, T. T. Fu, et al. (2019). Genomic
2718 and Transcriptomic Investigations of the Evolutionary Transition from Oviparity to
2719 Viviparity. *Proceedings of the National Academy of Sciences* **116**(9), 3646-3655.
- 2720 García-Collazo, R., M. Villagrán-Santa Cruz, E. Morales-Guillaumin, R. N. M. Lázaro, and F. R.
2721 Méndez-De La Cruz. (2012). Egg Retention and Intrauterine Embryonic Development in
2722 *Sceloporus aeneus* (Reptilia: Phrynosomatidae): Implications for the Evolution of
2723 Viviparity. *Revista Mexicana de Biodiversidad* **83**(3), 802–8.
- 2724 Gautron, J., M. T. Hincke, and Y. Nys. 1997. Precursor Matrix Proteins in the Uterine Fluid
2725 Change with Stages of Eggshell Formation in Hens. *Connective Tissue Research* **36**(3),
2726 195–210.

- 2727 Gautron, J., M. T. Hincke, M. Panhéleux, J. M. Garcia-Ruiz, T. Boldicke, and Y. Nys. (2001).
2728 Ovotransferrin Is a Matrix Protein of the Hen Eggshell Membranes and Basal Calcified
2729 Layer. *Connect Tissue Res* **42**(4), 255–67.
- 2730 Gautron, J., L. Stapane, N. le Roy, Y. Nys, A. B. Rodriguez-Navarro, and M. T. Hincke. (2021).
2731 Avian Eggshell Biomineralization: An Update on Its Structure, Mineralogy and Protein
2732 Tool Kit. *BMC Molecular and Cell Biology* **22**(11).
- 2733 Gautron, J., M. T. Hincke, K. Mann, M. Panhéleux, M. Bain, M. D. McKee, S. E. Solomon, and
2734 Y. Nys. (2001). Ovocalyxin-32, a Novel Chicken Eggshell Matrix Protein. Isolation,
2735 Amino Acid Sequencing, Cloning, and Immunocytochemical Localization. *Journal of*
2736 *Biological Chemistry* **276**(42), 39243–52.
- 2737 Gautron, J., E. Murayama, A. Vignal, M. Morisson, M. D. McKee, S. Réhault, V. Labas, et al.
2738 (2007). Cloning of Ovocalyxin-36, a Novel Chicken Eggshell Protein Related to
2739 Lipopolysaccharide-Binding Proteins, Bactericidal Permeability-Increasing Proteins, and
2740 Plunc Family Proteins. *Journal of Biological Chemistry* **282**(8), 5273–86.
- 2741 Geisert, R. D., Johns, D. N., Pfeiffer, C. A., Sullivan, R. M., Lucas, C. G., Simintiras, C. A., ... &
2742 Prather, R. S. (2023). Gene editing provides a tool to investigate genes involved in
2743 reproduction of pigs. *Molecular Reproduction and Development* **90**(7), 459-468.
- 2744 Ghorai, S.M., Priyam, M. (2018). Reptilia: Cellular Immunity in Reptiles: Perspective on
2745 Elements of Evolution. In: Cooper, E. (eds) *Advances in Comparative Immunology*.
2746 Springer, Cham. 773–91.

- 2747 Ghosh, J., C. M. Lun, A. J. Majeske, S. Sacchi, C. S. Schrankel, and L. C. Smith. (2011).
2748 Invertebrate Immune Diversity. *Developmental & Comparative Immunology* **35**(9), 959–
2749 74.
- 2750 Giansanti, F., M. F. Giardi, and D. Botti. (2006). Avian Cytokines-an Overview. *Current*
2751 *Pharmaceutical Design* **12**(24), 3083–99.
- 2752 Gibson, J. M., J. D. Aplin, A. White, and M. Westwood. (2001). Regulation of IGF
2753 Bioavailability in Pregnancy. *Molecular Human Reproduction* **7**(1),79-87
- 2754 Gilbert, S. F. (2010). Birds and Mammals: Early Development and Axis Formation.
2755 *Developmental Biology, 9th Ed. Sunderland, MA: Sinauer Associates, 287–322.*
- 2756 Girardi, G., Lingo, J. J., Fleming, S. D., & Regal, J. F. (2020). Essential role of complement in
2757 pregnancy: from implantation to parturition and beyond. *Frontiers in immunology* **11**,
2758 1681.
- 2759 Girling, J. E., A. Cree, and L. J. Guillette. (1997). Oviductal Structure in a Viviparous New
2760 Zealand Gecko, *Hoplodactylus maculatus*. *Journal of Morphology* **234**(1), 51–68.
- 2761 Girling, J. E. (2002). The Reptilian Oviduct: A Review of Structure and Function and Directions
2762 for Future Research. *Journal of Experimental Zoology* **293**(2), 141–70.
- 2763 Girling, J. E., and S. M. Jones. (2003). In Vitro Progesterone Production by Maternal and
2764 Embryonic Tissues during Gestation in the Southern Snow Skink (*Niveoscincus*
2765 *microlepidotus*). *General and Comparative Endocrinology* **133**(1), 100–108.

- 2766 Girling, J. E., A. Cree, and L. J. Jr. Guillette. (1998). Oviducal Structure in Four Species of
2767 Gekkonid Lizard Differing in Parity Mode and Eggshell Structure. *Reproduction,*
2768 *Fertility and Development Contraceptives* **10**(2),139-154.
- 2769 Gitlin, D., J. Kumate, J. Urrusti, and C. Morales. (1965). The Selectivity of the Human Placenta
2770 in the Transfer of Plasma Proteins from Mother to Fetus. *Obstetrical and Gynecological*
2771 *Survey* **20**(2), 217–20.
- 2772 Glazier, J. D., D. E. Atkinson, K. L. Thornburg, P. T. Sharpe, D. Edwards, R. D. H. Boyd, and C.
2773 P. Sibley. (1992). Gestational Changes in Ca²⁺ Transport across Rat Placenta and
2774 MRNA for Calbindin(9K) and Ca²⁺-ATPase. *American Journal of Physiology -*
2775 *Regulatory Integrative and Comparative Physiology* **262**, R930-R935
- 2776 González, Á., V. Rebmann, J. LeMaoult, P. A. Horn, E. D. Carosella, and E. Alegre. (2012). The
2777 Immunosuppressive Molecule HLA-G and Its Clinical Implications. *Critical Reviews in*
2778 *Clinical Laboratory Sciences* **49**(3), 63–84.
- 2779 Graham, S. P., R. L. Earley, C. Guyer, and M. T. Mendonça. (2011). Innate Immune
2780 Performance and Steroid Hormone Profiles of Pregnant versus Nonpregnant
2781 Cottonmouth Snakes (*Agkistrodon piscivorus*). *General and Comparative Endocrinology*
2782 **174**(3), 348–53.
- 2783 Grammatopoulos, D., G. N. Milton, and E. W. Hillhouse. (1994). The Human Myometrial CRH
2784 Receptor: G Proteins and Second Messengers. *Molecular and Cellular Endocrinology*
2785 **99**(2), 245–50.

- 2786 Grammatopoulos, D., E. W. Hillhouse, G. M. Stirrat, and S. A. Williams (1996). The Biological
2787 Activity of the Corticotropin-Releasing Hormone Receptor-Adenylate Cyclase Complex
2788 in Human Myometrium Is Reduced at the End of Pregnancy. *Journal of Clinical*
2789 *Endocrinology and Metabolism* **81**(2), 745–51.
- 2790 Gray, C. A., R. C. Burghardt, G. A. Johnson, F. W. Bazer, and T. E. Spencer. (2002). Evidence
2791 That Absence of Endometrial Gland Secretions in Uterine Gland Knockout Ewes
2792 Compromises Conceptus Survival and Elongation. *Reproduction-Cambridge* **124**(2),
2793 289–300.
- 2794 Gray, C. A., F. F. Bartol, B. J. Tarleton, A. A. Wiley, G. A. Johnson, F. W. Bazer, and T. E.
2795 Spencer. (2001). Developmental Biology of Uterine Glands. *Biology of Reproduction* **65**,
2796 1311–23.
- 2797 Grey, H. M. (1963). Phylogeny of the Immune Response: Studies on Some Physical Chemical
2798 and Serologic Characteristics of Antibody Produced in the Turtle. *The Journal of*
2799 *Immunology* **91**(6), 819–25.
- 2800 Griffith, O. W., J. U. van Dyke, and M. B. Thompson. (2013). No Implantation in an Extra-
2801 Uterine Pregnancy of a Placentotrophic Reptile. *Placenta* **34**(6), 510–11.
- 2802 Griffith, O. W., D. G. Blackburn, M. C. Brandley, J. U. van Dyke, C. M. Whittington, and M. B.
2803 Thompson. (2015). Ancestral State Reconstructions Require Biological Evidence to Test
2804 Evolutionary Hypotheses: A Case Study Examining the Evolution of Reproductive Mode
2805 in Squamate Reptiles. *Journal of Experimental Zoology* **324**(6), 493–503.

2806 Griffith, O. W., M. C. Brandley, K. Belov, and M. B. Thompson. (2016). Reptile Pregnancy Is
2807 Underpinned by Complex Changes in Uterine Gene Expression: A Comparative Analysis
2808 of the Uterine Transcriptome in Viviparous and Oviparous Lizards. *Genome Biology and*
2809 *Evolution* **8**(10), 3226–39.

2810 Griffith, O. W., M. C. Brandley, C. M. Whittington, K. Belov, and M. B. Thompson. (2017).
2811 Comparative Genomics of Hormonal Signaling in the Chorioallantoic Membrane of
2812 Oviparous and Viviparous Amniotes. *General and Comparative Endocrinology* **244**,19–
2813 29.

2814 Griffith, O. W., A. R. Chavan, S. Protopapas, J. Maziarz, R. Romero, and G. P. Wagner.
2815 (2017). Embryo Implantation Evolved from an Ancestral Inflammatory Attachment
2816 Reaction. *Proceedings of the National Academy of Sciences* **114**(32), E6566–75.

2817 Griffith, O. W., B. Ujvari, K. Belov, and M. B. Thompson. (2013). Placental Lipoprotein Lipase
2818 (LPL) Gene Expression in a Placentotrophic Lizard, *Pseudemoia entrecasteauxii*. *Journal*
2819 *of Experimental Zoology Part B: Molecular and Developmental Evolution* **320**(7): 465–
2820 70.

2821 Griffith, O. W., and G. P. Wagner. (2017). The Placenta as a Model for Understanding the Origin
2822 and Evolution of Vertebrate Organs. *Nature Ecology and Evolution* **1**(4).

2823 Griffith, O. W., Chavan, A. R., Pavlicev, M., Protopapas, S., Callahan, R., Maziarz, J., & Wagner,
2824 G. P. (2019). Endometrial recognition of pregnancy occurs in the grey short-tailed opossum
2825 (*Monodelphis domestica*). *Proceedings: Biological Sciences* **286**(1905), 1–9.

- 2826 Guarino, F. M., L. Paulesu, A. Cardone, L. Bellini, G. Ghiara, and F. Angelini. (1998).
2827 Endocrine Activity of the Corpus Luteum and Placenta during Pregnancy in *Chalcides*
2828 *chalcides* (Reptilia, Squamata). *General and Comparative Endocrinology* **111**(3), 261–
2829 70.
- 2830 Guillette, L. J. Jr, and R. E. Jones. 1980. Arginine Vasotocin-induced in Vitro Oviductal
2831 Contractions in *Anolis carolinensis*: Effect of Steroid Hormone Pretreatment in Vivo.
2832 *Journal of Experimental Zoology* **212**(1), 147–52.
- 2833 Guillette, L. J. Jr. (1992). Morphology of the Reproductive Tract in a Lizard Exhibiting Incipient
2834 Viviparity (*Sphenomorphus fragilis*) and Its Implications for the Evolution of the Reptilian
2835 Placenta. *Journal of Morphology* **212**(2), 163–73.
- 2836 Guillette, L. J. Jr., K. A. Bjorndal, A. B. Bolten, T. S. Gross, B. D. Palmer, B. E. Witherington,
2837 and J. M. Matter. (1991). Plasma Estradiol-17 β , Progesterone, Prostaglandin F, and
2838 Prostaglandin E2 Concentrations during Natural Oviposition in the Loggerhead Turtle
2839 (*Caretta caretta*). *General and Comparative Endocrinology* **82**(1), 121–30.
- 2840 Guillette, Louis L. J. Jr., V. Demarco, B. D. Palmer, and G. R. Masson. (1992). Effects of
2841 Arachidonic Acid, Prostaglandin F2, Prostaglandin E2, and Arginine Vasotocin on
2842 Induction of Birth in Viva and in Vitro in a Viviparous Lizard (*Sceloporus jarrovi*). *General*
2843 *and Comparative Endocrinology* **85**, 477–85.
- 2844 Guillette, L. J. Jr., S. L. Fox, and B. D. Palmer. (1989). Oviductal Morphology and Egg Shelling
2845 in the Oviparous Lizards *Crotaphytus collaris* and *Eumeces obsoletus*. *Journal of*
2846 *Morphology* **201**(2), 145–59.

- 2847 Guillette, L. J. Jr., and R. E. Jones. (1985). Ovarian, Oviductal, and Placental Morphology of the
2848 Reproductively Bimodal Lizard, *Sceloporus Aeneus*. *Journal of Morphology* **184**(1), 85–98.
- 2849 Gutsche, S., M. von Wolff, T. Strowitzki, and C. J. Thaler. (2003). Seminal Plasma Induces
2850 mRNA Expression of IL-1 β , IL-6 and LIF in Endometrial Epithelial Cells in Vitro.
2851 *Molecular Human Reproduction* **9**(12), 785–91.
- 2852 Hackmon, R., L. Pinnaduwage, J. Zhang, S. J. Lye, D. E. Geraghty, and C. E. Dunk. (2017).
2853 Definitive Class I Human Leukocyte Antigen Expression in Gestational Placentation: HLA-
2854 F, HLA-E, HLA-C, and HLA-G in Extravillous Trophoblast Invasion on Placentation,
2855 Pregnancy, and Parturition. *American Journal of Reproductive Immunology* **77**(6), 1–11.
- 2856 Hadi, H. A., C. A. Hodson, and D. Strickland. (1994). Premature Rupture of the Membranes
2857 between 20 and 25 Weeks' Gestation: Role of Amniotic Fluid Volume in Perinatal
2858 Outcome. *American Journal of Obstetrics and Gynecology* **170**(4), 1139–44.
- 2859 Haggarty P. (2002). Placental Regulation of Fatty Acid Delivery and Its Effect on Fetal Growth--
2860 a Review. *Placenta*. **23**, S28-38.
- 2861 Haider, S., and M. Knöfler. (2009). Human Tumour Necrosis Factor: Physiological and
2862 Pathological Roles in Placenta and Endometrium. *Placenta* **30**(2), 111–23.
- 2863 Haimovici, F., J. A. Hill, and D. J. Anderson. (1991). The Effects of Immunological Cytokines
2864 on Mouse Blastocyst Implantation in Vitro. *Biology of Reproduction* **44**, 69–75.

- 2865 Haluska, G. J., F. Z. Stanczyk, M. J. Cook, and M. J. Novy. (1987). Temporal Changes in
2866 Uterine Activity and Prostaglandin Response to RU486 in Rhesus Macaques in Late
2867 Gestation. *American Journal of Obstetrics and Gynecology* 157(6), 1487–95.
- 2868 Hamilton, R. M. G. (1986). The Microstructure of the Hen’ s Egg Shell -A Short Review. *Food*
2869 *Structure* 5(1), 99–110.
- 2870 Han, H. I., S. H. Lee, E. J. Song, S. Lee, H. T. Cheong, B. K. Yang, and C. K. Park. (2016).
2871 Effect of Uterine Histotroph on Embryo Development in Pigs. *Journal of Embryo Transfer*
2872 31(3), 199–205.
- 2873 Hanna, J., D. Goldman-Wohl, Y. Hamani, I. Avraham, C. Greenfield, S. Natanson-Yaron, D.
2874 Prus, et al. (2006). Decidual NK Cells Regulate Key Developmental Processes at the
2875 Human Fetal-Maternal Interface. *Nature Medicine* 12(9), 1065–74.
- 2876 Hansen, V. L., L. S. Faber, A. A. Salehpoor, and R. D. Miller. (2017). A Pronounced Uterine
2877 Pro-Inflammatory Response at Parturition Is an Ancient Feature in Mammals. *Proceedings*
2878 *of the Royal Society* 284(1865), 20171694
- 2879 Hansen, V. L., F. D. Schilkey, and R. D. Miller. (2016). Transcriptomic Changes Associated
2880 with Pregnancy in a Marsupial, the Gray Short-Tailed Opossum *Monodelphis Domestica*.
2881 *PLoS ONE* 11(9), 1–25.
- 2882 Hardison, R. (1998). Hemoglobins from Bacteria to Man: Evolution of Different Patterns of
2883 Gene Expression. *The Journal of Experimental Biology* 1117, 1099–1117.

- 2884 Harrington, S., and T. W. Reeder. (2017). Rate Heterogeneity across Squamata, Misleading
2885 Ancestral State Reconstruction and the Importance of Proper Null Model Specification.
2886 *Journal of Evolutionary Biology* **30**(2), 313–25.
- 2887 Hedley, M. L., B. L. Drake, J. R. Head, P. W. Tucker, and J. Forman. (1989). Differential
2888 Expression of the Class I MHC Genes in the Embryo and Placenta during Midgestational
2889 Development in the Mouse. *The Journal of Immunology* **142**(11), 4046–53.
- 2890 Hempstock, J., T. Cindrova-Davies, E. Jauniaux, and G. J. Burton. (2004). Endometrial Glands
2891 as a Source of Nutrients, Growth Factors and Cytokines during the First Trimester of
2892 Human Pregnancy: A Morphological and Immunohistochemical Study. *Reproductive*
2893 *Biology and Endocrinology* **2**, 1–14.
- 2894 Hendrawan, K., C. M. Whittington, M. C. Brandley, K. Belov, and M. B. Thompson. (2017).
2895 The Regulation of Uterine Proinflammatory Gene Expression during Pregnancy in the Live-
2896 Bearing Lizard, *Pseudemoia entrecasteauxii*. *Journal of Experimental Zoology Part B:*
2897 *Molecular and Developmental Evolution* **328**(4), 334–46.
- 2898 Herbert, J., M. B. Thompson, and L. A. Lindsay. (2006). Calcium Transport across the Uterine
2899 Epithelium of Pregnant Lizards. *Herpetological Monographs* **20**(1), 1–63.
- 2900 Hernández-Díaz, N., R. Torres, and M. Patricia Ramírez-Pinilla. (2017). Proteomic Profile of
2901 Mabuya Sp. (Squamata: Scincidae) Ovary and Placenta During Gestation. *Journal of*
2902 *Experimental Zoology Part B: Molecular and Developmental Evolution* **328**(4), 371–89.
- 2903 Hernández-Hernández, A., A. B. Rodríguez-Navarro, J. Gómez-Morales, C. Jiménez-López, Y.
2904 Nys and J. Manuel García-Ruiz. (2008). Influence of Model Globular Proteins with

- 2905 Different Isoelectric Points on the Precipitation of Calcium Carbonate. *Crystal Growth &*
2906 *Design* **8**, 1495-1502.
- 2907 Hernández-Hernández, A., J. Gómez-Morales, A. B. Rodríguez-Navarro, J. Gautron, Y. Nys, and
2908 J. M. García-Ruiz. (2008). Identification of Some Active Proteins in the Process of Hen
2909 Eggshell Formation. *Crystal Growth and Design* **8**(12), 4330–39.
- 2910 Hernández-Hernández, A., M. L. Vidal, J. Gómez-Morales, A. B. Rodríguez-Navarro, V. Labas,
2911 J. Gautron, Y. Nys, and J. M. García Ruiz. (2008). Influence of Eggshell Matrix Proteins on
2912 the Precipitation of Calcium Carbonate (CaCO₃). *Journal of Crystal Growth* **310**(7–9),
2913 1754–59.
- 2914 Hertelendy, F., M. Yeh, and H. v. Biellier. (1974). Induction of Oviposition in the Domestic Hen
2915 by Prostaglandins. *General and Comparative Endocrinology* **22**(4), 529–31.
- 2916 Heulin, B. (1990). Étude Comparative de La Membrane Coquillère Chez Les Souches Ovipare et
2917 Vivipare Du Léopard Lacerta Vivipara. *Canadian Journal of Zoology*.
- 2918 Heulin, B., S. Ghielmi, N. Vogrin, Y. Surget-Groba, and C. P. Guillaume. (2002). Variation in
2919 Eggshell Characteristics and in Intrauterine Egg Retention between Two Oviparous Clades
2920 of the Lizard Lacerta Vivipara: Insight into the Oviparity-Viviparity Continuum in
2921 Squamates. *Journal of Morphology* **252**(3), 255–62.
- 2922 Heulin, B., J. R. Stewart, Y. Surget-Groba, P. Bellaud, and F. Jouan. (2005). Development of the
2923 Uterine Shell Glands During the Preovulatory and Early Gestation Periods in Oviparous and
2924 Viviparous Lacerta vivipara *Journal of Morphology* **266**(1), 80–93.

- 2925 Higashi, T., S. Tokuda, S. I. Kitajiri, S. Masuda, H. Nakamura, Y. Oda, and M. Furuse. (2013).
2926 Analysis of the 'angulin' Proteins LSR, ILDR1 and ILDR2 - Tricellulin Recruitment,
2927 Epithelial Barrier Function and Implication in Deafness Pathogenesis. *Journal of Cell*
2928 *Science* **126**(16), 3797.
- 2929 Hill, J. A. (1992). Cytokines Considered Critical in Pregnancy. *American Journal of*
2930 *Reproductive Immunology* **28**(3-4), 123–26.
- 2931 Hillhouse, E. W., Grammatopoulos D. K. (2001) Control of intracellular signalling by
2932 corticotropin-releasing hormone (CRH) in human myometrium. *Frontiers of Hormone*
2933 *Resesearch* 27:66 –74
- 2934 Hincke, M. T., J. Gautron, C. P. W. Tsang, M. D. McKee, and Y. Nys. (1999). Molecular
2935 Cloning and Ultrastructural Localization of the Core Protein of an Eggshell Matrix
2936 Proteoglycan, Ovocleidin-116. *Journal of Biological Chemistry* **274**(46), 32915–23.
- 2937 Hincke, M. T., Y. Nys, J. Gautron, A. B. Rodriguez-Navarro, K. Mann, and M. D. McKee.
2938 (2012). The Eggshell: Structure, Composition and Mineralization. *Frontiers in Bioscience*
2939 **17**(4), 1266–80.
- 2940 Hincke, M. T., O. Wellman-Labadie, M. D. McKee, J. Gautron, Y. Nys, and K. Mann. (2008).
2941 Biosynthesis and Structural Assembly of Eggshell Components. In Y. Mine (Eds.) *Egg*
2942 *Bioscience and Biotechnology* (pp. 97–128). Wiley-Interscience.
- 2943 Ho, S. M. (1987). Endocrinology of vitellogenesis. In D. O. Norris & R. E. Jones (Eds.)
2944 *Hormones and reproduction in fishes, amphibians, and reptiles* (pp. 145-169). Springer.

- 2945 Hodges, W. L. (2004). Evolution of Viviparity in Horned Lizards (Phrynosoma): Testing the
2946 Cold-Climate Hypothesis. *Journal of Evolutionary Biology* **17**(6), 1230–37.
- 2947 Hoenderop, J. G. J., B. Nilius, and R. J. M. Bindels. (2005). Calcium Absorption across
2948 Epithelia. *Physiological Reviews* **85**(1), 373–422.
- 2949 Hubrecht, A. A. W. (1910). Memoirs: the fetal membranes of the vertebrates. *Journal of Cell*
2950 *Science*. **2**, 177–188.
- 2951 Hughes, R. L. (1984). Structural Adaptations of the Eggs and the Fetal Membranes of
2952 Monotremes and Marsupials for Respiration and Metabolic Exchange. In: Seymour, R.S.
2953 (Eds.) *Respiration and Metabolism of Embryonic Vertebrates. Perspectives in vertebrate*
2954 *science* (pp. 389–421). Springer.
- 2955 Hunt, J. S., J. L. Pace, P. J. Morales, and C. Ober. (2003). Immunogenicity of the Soluble
2956 Isoforms of HLA-G. *Molecular Human Reproduction* **9**(11): 729–35.
- 2957 Hunt, J. S., M. G. Petroff, R. H. McIntire, and C. Ober. (2005). HLA-G and Immune Tolerance
2958 in Pregnancy. *The Federation of American Societies of Experimental Biology Journal* **19**(7):
2959 681–93.
- 2960 Husslein, P. (1984). The Importance of Oxytocin and Prostaglandins to the Mechanism of Labor
2961 in Humans. *Wiener Klinische Wochenschrift* **155**, 1–32.
- 2962 Hviid, T. V. F., S. Hylenius, A. Lindhard, and O. B. Christiansen. (2004) Association between
2963 Human Leukocyte Antigen-G Genotype and Success of in Vitro Fertilization and Pregnancy
2964 Outcome. *Tissue Antigens* **64**(1), 66–69.

- 2965 Iida, A., Hiroyuki N. A., Y. Someya, M. Inokuchi, T. A. Onuma, H. Yokoi, T. Suzuki, E. Hondo,
2966 and K. Sano. (2019) Mother-to-Embryo Vitellogenin Transport in a Viviparous Teleost
2967 *Xenotoca Eiseni*. *Proceedings of the National Academy of Sciences* **116**(44), 22359–65.
- 2968 Ikenouchi, J., M. Furuse, K. Furuse, H. Sasaki, Sa. Tsukita, and Sh. Tsukita. (2005). Tricellulin
2969 Constitutes a Novel Barrier at Tricellular Contacts of Epithelial Cells. *Journal of Cell*
2970 *Biology* **171**(6), 939–45.
- 2971 Ilicic, M., T. Butler, T. Zakar, and J. W. Paul. (2017). The Expression of Genes Involved in
2972 Myometrial Contractility Changes during Ex Situ Culture of Pregnant Human Uterine
2973 Smooth Muscle Tissue. *Journal of Smooth Muscle Research* **53**(1): 73–89.
- 2974 Ingram, G. A., and D. H. Molyneux. (1983). The Humoral Immune Response of the Spiny-
2975 Tailed Agamid Lizard (*Agama caudospinosum*) to Injection with *Leishmania* *Agamae*
2976 Promastigotes. *Veterinary Immunology and Immunopathology* **4**(4), 479–91.
- 2977 Iozzo, R. V., & L. Schaefer. (2015). Proteoglycan form and function: A comprehensive
2978 nomenclature of proteoglycans. *Matrix biology: Journal of the International Society for*
2979 *Matrix Biology* **42**, 11–55.
- 2980 Ishitani, A., N. Sageshima, N. Lee, N. Dorofeeva, K. Hatake, H. Marquardt, and D. E. Geraghty.
2981 (2003). Protein Expression and Peptide Binding Suggest Unique and Interacting Functional
2982 Roles for HLA-E, F, and G in Maternal-Placental Immune Recognition. *The Journal of*
2983 *Immunology* **171**(3), 1376–84.

- 2984 Jenkins, N. K., and K. Simkiss. (1968). The Calcium and Phosphate Metabolism of Reproducing
2985 Reptiles with Particular Reference to the Adder (*Vipera Berus*). *Comparative Biochemistry*
2986 *and Physiology* **26**(3).
- 2987 Jeong, J., A. U. Rao, J. Xu, S. L. Ogg, Y. Hathout, C. Fenselau, and I. H. Mather. (2009). The
2988 PRY/SPRY/B30.2 Domain of Butyrophilin 1A1 (BTN1A1) Binds to Xanthine
2989 Oxidoreductase. *Journal of Biological Chemistry* **284**(33), 22444–56.
- 2990 Jerez, A., and M. P. Ramírez-Pinilla. (2001). The Allantoplacenta of *Mabuya mabouya* (Sauria,
2991 Scincidae). *Journal of Morphology* **249**(2), 132–46.
- 2992 Ji, X., and W. G. Du. (2001). The Effects of Thermal and Hydric Environments on Hatching
2993 Success, Embryonic Use of Energy and Hatchling Traits in a Colubrid Snake, *Elaphe*
2994 *carinata*. *Comparative Biochemistry and Physiology - A Molecular and Integrative*
2995 *Physiology* **129**(2–3), 461–71.
- 2996 Ji, X., C. X. Lin, L. H. Lin, Q. B. Qiu, and Y. Du. (2007). Evolution of Viviparity in Warm-
2997 Climate Lizards: An Experimental Test of the Maternal Manipulation Hypothesis. *Journal*
2998 *of Evolutionary Biology* **20**(3), 1037–45.
- 2999 Jiang, B., Y. He, A. Elsler, S. Wang, J. N. Keating, J. Song, J., S. L. Kearns, and M. J. Benton
3000 (2023). Extended embryo retention and viviparity in the first amniotes. *Nature Ecology &*
3001 *Evolution* **7**, 1131-1140
- 3002 Johnston, H., I. Koukoulas, K. Jeyaseelan, A. Armugam, L. Earnest, R. Baird, N. Dawson, T.
3003 Ferraro, and E. M. Wintour. (2000). Ontogeny of Aquaporins 1 and 3 in Ovine Placenta and
3004 Fetal Membranes. *Placenta* **21**(1), 88–99.

3005 Jonchère, V., S. Rehault-Godbert, C. Hennequet-Antier, C. Cabau, V. Sibut, L. A. Cogburn, Y.
3006 Nys, and J. Gautron. (2010). Gene Expression Profiling to Identify Eggshell Proteins
3007 Involved in Physical Defense of the Chicken Egg. *BMC Genomics* **11**, 57.

3008 Jonchère, V., A. Brionne, J. Gautron, and Y. Nys. (2012). Identification of Uterine Ion
3009 Transporters for Mineralization Precursors of the Avian Eggshell. *BMC Physiology* **12**(10).

3010 Jones, R. E., and L. J. Guillette. (1982). Hormonal Control of Oviposition and Parturition in
3011 Lizards. *Herpetologica* **38**(1), 80–93.

3012 Jones, R. E., K. H. Lopez, C. H. Summers, and H. B. Austin. (1987). Seasonal Changes in the
3013 Effects of Arginine Vasotocin and Stretch on Anolis Uterine Contractions in Vitro. *Journal*
3014 *of Experimental Zoology* **242**(2), 233–39.

3015 Jonsson, A. M., M. Uzunel, C. Götherström, N. Papadogiannakis, and M. Westgren. (2008).
3016 Maternal Microchimerism in Human Fetal Tissues. *American Journal of Obstetrics and*
3017 *Gynecology* **198**(3), 325.e1-325.e6.

3018 Joosten, I., M. F. Sanders, and E. J. Hensen. (1991). Involvement of Major Histocompatibility
3019 Complex Class I Compatibility between Dam and Calf in the Aetiology of Bovine Retained
3020 Placenta. *Animal Genetics* **22**(6), 455–63.

3021 Kämmerer, U., L. Rieger, A. Honig, and E. Kämpgen. (2006). Characterization of Human
3022 Dendritic Cells at the Materno-Fetal Interface. In *Immunology of Pregnancy* 122–29.
3023 Springer.

3024 Kampmann, U., S. Knorr, J. Fuglsang, and P. Ovesen. (2019). Determinants of Maternal Insulin
3025 Resistance during Pregnancy: An Updated Overview. *Journal of Diabetes Research*.

3026 Kao, C. Y., and J. R. McCullough. (1975). Ionic Currents in the Uterine Smooth Muscle. *Journal*
3027 *of Physiology* **246**, 1–36.

3028 Karteris, E., D. Grammatopoulos, Y. Dai, K. B. Olah, T. B. Ghobara, A. Easton, and E. W.
3029 Hillhouse. (1998). The Human Placenta and Fetal Membranes Express the Corticotropin-
3030 Releasing Hormone Receptor 1 α (CRH-1 α) and the CRH-C Variant Receptor. *Journal of*
3031 *Clinical Endocrinology and Metabolism* **83**(4), 1376–79.

3032 Kawagoe, T., S. Sato, K. Matsushita, H. Kato, K. Matsui, Y. Kumagai, T. Saitoh, T. Kawai, O.
3033 Takeuchi, and S. Akira. (2008). Sequential Control of Toll-like Receptor–Dependent
3034 Responses by IRAK1 and IRAK2. *Nature Immunology* **9**(6), 684.

3035 Kayisli, U. A., B. Selam, O. Guzeloglu-Kayisli, R. Demir, and A. Arici. (2003). Human
3036 Chorionic Gonadotropin Contributes to Maternal Immunotolerance and Endometrial
3037 Apoptosis by Regulating Fas-Fas Ligand System. *The Journal of Immunology* **171**(5),
3038 2305–13.

3039 Kelly, R. W. (1995). Contraception: Immunosuppressive Mechanisms in Semen: Implications for
3040 Contraception. *Human Reproduction* **10**(7), 1686–93.

3041 Khosrotehrani, K., K. L. Johnson, S. Gu, H. Stroh, and D. W. Bianchi. (2005). Natural History of
3042 Fetal Cell Microchimerism during and Following Murine Pregnancy. *Journal of*
3043 *Reproductive Immunology* **66**, 1–12.

- 3044 Kieffer, T. E. C., A. Laskewitz, S. A. Scherjon, M. M. Faas, and J. R. Prins. (2019). Memory T
3045 Cells in Pregnancy. *Frontiers in Immunology* **10**(APR).
- 3046 King, A., T. D. Burrows, S. E. Hiby, J. M. Bowen, S. Joseph, S. Verma, P. B. Lim, et al. (2000).
3047 Surface Expression of HLA-C Antigen by Human Extravillous Trophoblast. *Placenta* **21**
3048 (4): 376–87.
- 3049 King, A., D. S. J. Allan, M. Bowen, S. J. Powis, S. Joseph, S. Verma, S. E. Hiby, A. J.
3050 Mcmichael, Y. Wai. Loke, and M. Braud. (2000). HLA-E Is Expressed on Trophoblast and
3051 Interacts with CD94 / NKG2 Receptors on Decidual NK Cells. *European Journal of*
3052 *Immunology* **30**(6), 1623–31.
- 3053 King, A., C. Birkby, and Y. W. Loke. (1989). Early Human Decidual Cells Exhibit NK Activity
3054 against the K562 Cell Line but Not against First Trimester Trophoblast. *Cellular*
3055 *Immunology* **118**(2), 337–44.
- 3056 King, B. F., and J. M. Wilson. (1983). A Fine Structural and Cytochemical Study of the Rhesus
3057 Monkey Yolk Sac: Endoderm and Mesothelium. *The Anatomical Record* **205**(2), 143–58.
- 3058 King, N. J. C., B. L. Drake, L. E. Maxwell, and J. C. Rodger. (1987). Class I Major
3059 Histocompatibility Complex Antigen Expression on Early Murine Trophoblast and Its
3060 Induction by Lymphokines in Vitro. II. The Role of Gamma Interferon in the Responses of
3061 Primary and Secondary Giant Cells. *Journal of Reproductive Immunology* **12**(1), 13–21.
- 3062 Klein, C., and M. H. T. Troedsson. (2011). Maternal Recognition of Pregnancy in the Horse: A
3063 Mystery Still to Be Solved. *Reproduction, Fertility and Development* **23**(8), 952–63.

3064 Klein, C. (2016). Journal of Equine Veterinary Science Maternal Recognition of Pregnancy in
3065 the Context of Equine Embryo Transfer. *Journal of Equine Veterinary Science* **41**, 22–28.

3066 Koo, T. H., H. Yang, B. S. An, K. C. Choi, S. H. Hyun, and E. B. Jeung. (2012). Calcium
3067 Transport Genes Are Differently Regulated in Maternal and Fetal Placenta in the Knockout
3068 Mice of Calbindin-D 9k and -D 28k. *Molecular Reproduction and Development* **79**(5), 346–
3069 55.

3070 Kovacs, C. S. (2015). Early Human Development Calcium, Phosphorus, and Bone Metabolism
3071 in the Fetus and Newborn. *Early Human Development* **91**(11). 623–28.

3072 Kovacs, C. S., B. Lanske, J. L. Hunzelman, J. Guo, A. C. Karaplis, and H. M. Kronenberg.
3073 (1996). Parathyroid Hormone-Related Peptide (PTHrP) Regulates Fetal-Placental Calcium
3074 Transport through a Receptor Distinct from the PTH/PTHrP Receptor. *Proceedings of the*
3075 *National Academy of Sciences* **93**(26), 15233–38.

3076 Kovats, S., E. K. Main, C. Librach, M. Stubblebine, J. Susan, R. Demars, J. Wang, et al. (1990).
3077 A Class I Antigen , HLA-G , Expressed in Human Trophoblasts *American Association for*
3078 *the Advancement of Science* **248**(4952), 220–23.

3079 Kuchling, G., and M. D. Hofmeyr. (2022). Too Hot to Nest? In a Hot Summer the Tortoise
3080 *Chersina angulata* Can Switch from Nesting to Facultative Viviparity. *Frontiers in Ecology*
3081 *and Evolution* **9**(Jan).

3082 Kumari, S. T. R., H. B.D. Sarkar, and T. Shivanandappa. (1992). Histological, Histochemical,
3083 and Biochemical Changes in the Annual Oviduct Cycle of the Agamid, *Calotes versicolor*.
3084 *Journal of Morphology* **211**(3): 295–306.

3085 Kuzmina, I. V. (2023). The yolk sac as the main organ in the early stages of animal embryonic
3086 development. *Frontiers in Physiology*, **14**, 1185286.

3087 Lafond, J., and L. Simoneau. (2006). Calcium Homeostasis in Human Placenta: Role of
3088 Calcium-Handling Proteins. *International Review of Cytology* **250**(06), 109–74.

3089 Lafontaine, L., P. Chaudhry, M. J. Lafleur, C. van Themsche, M. J. Soares, and E. Asselin.
3090 (2011). Transforming Growth Factor Beta Regulates Proliferation and Invasion of Rat
3091 Placental Cell Lines. *Biology of Reproduction* **84**(3), 553–59.

3092 Laird, M. K., M. B. Thompson, and C. M. Whittington. (2019). Facultative Oviparity in a
3093 Viviparous Skink (*Saiphos equalis*). *Biology Letters* **15**(4).

3094 Lakshminarayanan, R., E. O. Chi-Jin, X. J. Loh, R. M. Kini, and S. Valiyaveetil. (2005).
3095 Purification and Characterization of a Vaterite-Inducing Peptide, Pelovaterin, from the
3096 Eggshells of *Pelodiscus sinensis* (Chinese Soft-Shelled Turtle). *Biomacromolecules* **6**(3),
3097 1429–37.

3098 Lappas, M., and G. E. Rice. (2007). The Role and Regulation of the Nuclear Factor Kappa B
3099 Signalling Pathway in Human Labour. *Placenta* **28**(5–6), 543–56.

3100 Lappas, M., M. Permezel, H. M. Georgiou, and G. E. Rice. (2002). Nuclear Factor Kappa B
3101 Regulation of Proinflammatory Cytokines in Human Gestational Tissues in Vitro. *Biology
3102 of Reproduction* **67**(2), 668–73.

3103 Laurin, M. (2005). Embryo retention, character optimization, and the origin of the extra-
3104 embryonic membranes of the amniotic egg. *Journal of Natural History*. **39**, 3151–3161

- 3105 Larsson, A., D. Carlander, and M. Wilhelmsson. (1998). Antibody Response in Laying Hens
3106 with Small Amounts of Antigen. *Food and Agricultural Immunology* **10**(1), 29–36.
- 3107 Le Bouteiller, P., and Marie-Pierre Piccinni. (2008). Human NK Cells in Pregnant Uterus: Why
3108 There? *American Journal of Reproductive Immunology* **59**(5), 401–6.
- 3109 Le Roy, N., L. Stapane, J. Gautron, and M. T. Hincke. (2021). Evolution of the Avian Eggshell
3110 Biomineralization Protein Toolkit – New Insights from Multi-Omics. *Frontiers in Genetics*.
- 3111 Leadon, D. P., P. D. Rosedale, L. B. Jeffcott, and W. R. Allen. (1982). A Comparison of Agents
3112 for Inducing Parturition in Mares in the Pre-Viable and Premature Periods of Gestation.
3113 *Journal of Reproduction and Fertility* **32**, 597–602.
- 3114 Lee, M. S. Y., and P. Doughty. (1997). The Relationship between Evolutionary Theory and
3115 Phylogenetic Analysis. *Biological Reviews* **72**(4): 471–95.
- 3116 Lee, M. S. Y., and R. Shine. (1998). Reptilian Viviparity and Dollo’s Law. *Evolution* **52**(5):
3117 1441–50.
- 3118 Lee, S. Y., J. W. Anderson, G. L. Scott, and H. W. Mossman. (1983). Ultrastructure of the
3119 Placenta and Fetal Membranes of the Dog: II. The Yolk Sac. *American Journal of Anatomy*
3120 **166**(3), 313–27.
- 3121 Lefebvre, D. L., M. Piersanti, X. H. Bai, Z. Q. Chen, and S. J. Lye. (1995). Myometrial
3122 Transcriptional Regulation of the Gap Junction Gene, Connexin-43. *Reproduction, Fertility*
3123 *and Development* **7**(3), 603–11.

- 3124 Lefebvre, S., S. Berrih-Aknin, F. Adrian, P. Moreau, S. Poëa, L. Gourand, J. Dausset, E. D.
3125 Carosella, and P. Paul. (2001). A Specific Interferon (IFN)-Stimulated Response Element of
3126 the Distal HLA-G Promoter Binds IFN-Regulatory Factor 1 and Mediates Enhancement of
3127 This Nonclassical Class I Gene by IFN- β . *Journal of Biological Chemistry* **276**(9), 6133–
3128 39.
- 3129 Legendre, L. J., S. Choi, J. A. Clarke. (2022). The Diverse Terminology of Reptile Eggshell
3130 Microstructure and its Effect on Phylogenetic Comparative Analyses. *Journal of Anatomy*.
3131 **241**(3), 641-666.
- 3132 Leiphrakpam, P. D., P. P. Patil, N. Remmers, B. Swanson, P. M. Grandgenett, F. Qiu, F. Yu, P.
3133 Radhakrishnan. (2019). Role of keratan sulfate expression in human pancreatic cancer
3134 malignancy. *Scientific Reports* **9**, 9665.
- 3135 Lelong, C., M. Mathieu, and P. Favrel. (2000). Structure and Expression of MGDF, a New
3136 Member of the Transforming Growth Factor- β Superfamily in the Bivalve Mollusc
3137 *Crassostrea gigas*. *European Journal of Biochemistry* **267**(13), 3986–93.
- 3138 Li, X. H., A. H. Kishore, D. Dao, W. Zheng, C. A. Roman, and R. A. Word. (2010). A Novel
3139 Isoform of Microphthalmia-Associated Transcription Factor Inhibits IL-8 Gene Expression
3140 in Human Cervical Stromal Cells. *Molecular Endocrinology* **24**(8), 1512–28.
- 3141 Liabakk, N. B., E. Lien, A. Sundan, A. Sunde, R. Austgulen, and T. Espevik. (1993).
3142 Immunology: High Concentrations of the Soluble P55 Tumour Necrosis Factor Receptor in
3143 Human Seminal Plasma. *Human Reproduction* **8**(11), 1837–42.

- 3144 Lin, S. C., Y. C. Lo, and H. Wu. (2010). Helical Assembly in the MyD88-IRAK4-IRAK2
3145 Complex in TLR/IL-1R Signalling. *Nature* **465**(7300), 885–90.
- 3146 Lin, Y. P., and P. C. Singer. (2005). Inhibition of Calcite Crystal Growth by Polyphosphates.
3147 *Water Research* **39**(19), 4835–43.
- 3148 Lindau, R., J. Svensson-Arvelund, R. B. Mehta, D. Eklund, G. E. Lash, M C Jenmalm, and J
3149 Ernerudh. (2015). IL-34 at the Human Fetal–Maternal Interface. *Journal of Reproductive*
3150 *Immunology* **111**, 11–12.
- 3151 Lindegaard, M. L.S., G. Olivecrona, C. Christoffersen, D. Kratky, J. Hannibal, B. L. Petersen, R.
3152 Zechner, P. Damm, and L. B. Nielsen. (2005). Endothelial and Lipoprotein Lipases in
3153 Human and Mouse Placenta. *Journal of Lipid Research* **46**(11), 2339–46.
- 3154 Lindström, T. M., and P. R. Bennett. (2005). The Role of Nuclear Factor Kappa B in Human
3155 Labour. *Reproduction* **130**(5), 569–81.
- 3156 Linville, B. J., J. R. Stewart, T. W. Ecay, J. F. Herbert, S. L. Parker, and M. B. Thompson.
3157 (2010). Placental Calcium Provision in a Lizard with Prolonged Oviductal Egg Retention.
3158 *Journal of Comparative Physiology B: Biochemical, Systemic, and Environmental*
3159 *Physiology* **180**(2): 221–27.
- 3160 Liu, S., L. Diao, C. Huang, Y. Li, Y. Zeng, and J. Y.H. Kwak-Kim. (2017). The Role of
3161 Decidual Immune Cells on Human Pregnancy. *Journal of Reproductive Immunology* **124**,
3162 44–53.

- 3163 Lockwood, C. J. (2004). The Initiation of Parturition at Term. *Obstetrics and Gynecology Clinics*
3164 **31**(4), 935–47.
- 3165 Lourdais, O., Lorioux, S., Dupoué, A., Wright, C., & DeNardo, D. F. (2015). Embryonic water
3166 uptake during pregnancy is stage-and fecundity-dependent in the snake *Vipera aspis*.
3167 *Comparative Biochemistry and Physiology Part A: Molecular & Integrative Physiology*
3168 **189**, 102-106.
- 3169 Luu, K. C., G. Y. Nie, A. Hampton, G. Q. Fu, Y. X. Liu, and L. A. Salamonsen. (2004).
3170 Endometrial Expression of Calbindin (CaBP)-D28k but Not CaBP-D9k in Primates Implies
3171 Evolutionary Changes and Functional Redundancy of Calbindins at Implantation.
3172 *Reproduction* **128**(4), 433–41.
- 3173 Lynch, V. J., and G. P. Wagner. (2010). Did Egg-Laying Boas Break Dollo’s Law? Phylogenetic
3174 Evidence for Reversal to Oviparity in Sand Boas (*Eryx*: Boidae). *Evolution* **64**(1), 207–16.
- 3175 **Ma, L., Buckley, L. B., Huey, R. B., Du, W.-G., & Pincheira-Donoso, D.** (2018). A global test
3176 of the cold-climate hypothesis for the evolution of viviparity of squamate reptiles. *Global*
3177 *Ecology and Biogeography* **27**, 679–689.
- 3178 Mead, R., V. P. Eroschenko, D. R. Highfill. (1981). Effects of progesterone and estrogen on the
3179 histology of the oviduct of the garter snake, *Thamnophis elegans*. *Endocrinology* **45**(3),
3180 345-354.
- 3181 Madeja, Z., H. Yadi, R. Apps, S. Boulenouar, S. J. Roper, L. Gardner, A. Moffett, F. Colucci,
3182 and M. Hemberger. (2011). Paternal MHC Expression on Mouse Trophoblast Affects

3183 Uterine Vascularization and Fetal Growth. *Proceedings of the National Academy of*
3184 *Sciences* **108**(10), 4012–17.

3185 Makrigiannakis, A., M. Karamouti, P. Drakakis, D. Loutradis, and A. Antsaklis. (2008).
3186 Fetomaternal Immunotolerance. *American Journal of Reproductive Immunology* **60**(6),
3187 482–96.

3188 Manaster, I., and O. Mandelboim. (2010). The Unique Properties of Uterine NK Cells. *American*
3189 *Journal of Reproductive Immunology* **63**(6), 434–44.

3190 Mann, K., B. Maček, and J. V. Olsen. (2006). Proteomic Analysis of the Acid-Soluble Organic
3191 Matrix of the Chicken Calcified Eggshell Layer. *Proteomics* **6**(13), 3801–10.

3192 Marchalonis, J. J., E. H. M. Ealey, and E. Diener. (1969). Immune Response of the Tuatara,
3193 *Sphenodon punctatum*. *Australian Journal of Experimental Biology and Medical Science*
3194 **47**(3), 367–80.

3195 Marillat, R. I. E., O. Cases, K. T. Nguyen-Ba-Charvet, M. Tessier-Lavigne, C. Sotelo, and A.
3196 Che. (2002). Spatiotemporal Expression Patterns of Slit and Robo Genes in the Rat Brain
3197 *Journal of Comparative Neurology* **442**(2), 130–55.

3198 Masuhiro, K., E. Nishino, N. Matsuzaki, T. Kameda, T. Tanigushi, T. Takagi, F. Saji, and O.
3199 Tanizawa. 1990. Trophoblast-Derived Interleukin-6 (IL-6) Regulates Human Chorionic
3200 Gonadotropin Release through IL-6 Receptor on Human Trophoblasts. *The Journal of*
3201 *Clinical Endocrinology & Metabolism* **71**(2), 436–41.

- 3202 Mathies, T., and R. M. Andrews. (1999). Determinants of Embryonic Stage at Oviposition in the
3203 Lizard *Urosaurus ornatus*. *Physiological and Biochemical Zoology* **72**(6), 645–55.
- 3204 Mathies, T., and R. M. Andrews. (2000). Does Reduction of the Eggshell Occur Concurrently
3205 with or Subsequent to the Evolution of Viviparity in Phrynosomatid Lizards? *Biological*
3206 *Journal of the Linnean Society* **71**(719).
- 3207 Matschke, K., L. D. Silva-Azevedo, R. Hlushchuk, V. Djonov, and O. Baum. (2006). Annexins
3208 as Cell-Type-Specific Markers in the Developing Chicken Chorionallantoic Membrane.
3209 *Cell and Tissue Research* **323** (3): 395–404.
- 3210 Matzinger, P. (2007). Friendly and Dangerous Signals: Is the Tissue in Control? *Nature*
3211 *Immunology* **8**(1), 11–13.
- 3212 McLean, M., and R. Smith. (2001). Corticotrophin-Releasing Hormone and Human Parturition.
3213 *Reproduction* **121**(4), 493–501.
- 3214 Medawar, P. B. (1991). The Nobel Lectures in Immunology: The Nobel Prize for Physiology or
3215 Medicine, 1960. *Scandinavian Journal of Immunology* **33**(4), 337–44.
- 3216 Medawar, P. B. (1953). Some Immunological and Endocrinological Problems Raised by the
3217 Evolution of Viviparity in Vertebrates. In *Symposium for the Society of Experimental*
3218 *Biology* **7**, 320–37.
- 3219 Medeiros, D. M., and J. G. Crump. (2012). New Perspectives on Pharyngeal Dorsoventral
3220 Patterning in Development and Evolution of the Vertebrate Jaw. *Developmental Biology*
3221 **371**(2), 121–135.

- 3222 Mendelson, C. R. (2009). Minireview: Fetal-Maternal Hormonal Signaling in Pregnancy and
3223 Labor. *Molecular Endocrinology* **23**(7), 947–54.
- 3224 Mendelson, C. R., and J. C. Condon. (2005). New Insights into the Molecular Endocrinology of
3225 Parturition. *Journal of Steroid Biochemistry and Molecular Biology* **93**, 113–19.
- 3226 Mercado-Simmen, R. C., B. Goodwin, M. S. Ueno, S. Y. Yamamoto, and G. D. Bryant-
3227 Greenwod. (1982). Relaxin Receptors in the Myometrium of the Pig. *Biology of*
3228 *Reproduction* **26**, 120–28.
- 3229 Mercer, L. J., L. G. Brown, R. E. Petres, and R. H. Messer. (1984). A Survey of Pregnancies
3230 Complicated by Decreased Amniotic Fluid. *American Journal of Obstetrics and*
3231 *Gynecology* **149**(3), 355–61.
- 3232 Mesiano, S., E. C. Chan, J. T. Fitter, K. Kwek, G. Yeo, and R. Smith. (2002). Progesterone
3233 Withdrawal and Estrogen Activation in Human Parturition Are Coordinated by
3234 Progesterone Receptor an Expression in the Myometrium. *Journal of Clinical*
3235 *Endocrinology and Metabolism* **87**(6), 2924–30.
- 3236 Mesiano, S., Y. Wang, and E. R. Norwitz. (2011). Progesterone Receptors in the Human
3237 Pregnancy Uterus: Do They Hold the Key to Birth Timing? *Reproductive Sciences* **18**(1), 6–
3238 19.
- 3239 Metcalfe, J., and M. K. Stock. (1993). Oxygen Exchange in the Chorioallantoic Membrane,
3240 Avian Homologue of the Mammalian Placenta. *Placenta* **14**(6): 605–13.

- 3241 Miele, L., E. Cordella-Miele, and A. B. Mukherjee. (1987). Uteroglobin: Structure, Molecular
3242 Biology, and New Perspectives on Its Function as a Phospholipase A2 Inhibitor. *Endocrine*
3243 *Reviews* **8**(4), 474–90.
- 3244 Mikhailov, K. E. (1997). Fossil and Recent Eggshell in Amniotic Vertebrates: Fine Structure,
3245 Comparative Morphology and Classification Article. *Special Papers in Palaeontology* **56**.
- 3246 Mikšík, I., A. Eckhardt, P. Sedláková, and K. Mikulikova. (2007). Proteins of Insoluble Matrix
3247 of Avian (*Gallus gallus*) Eggshell. *Connective Tissue Research* **48**(1), 1–8.
- 3248 Mikšík, I., P. Sedláková, K. Lacinová, S. Pataridis, and A. Eckhardt. (2010). Determination of
3249 Insoluble Avian Eggshell Matrix Proteins. *Analytical and Bioanalytical Chemistry* **397**(1):
3250 205–14.
- 3251 Moffett, A., and Y. W. Loke. (2004). The Immunological Paradox of Pregnancy: A Reappraisal.
3252 *Placenta* **25**(1), 1–8.
- 3253 Moffett, A., F. Colucci. (2014). Uterine NK Cells: Active Regulators at the Maternal-Fetal
3254 Interface. *The Journal of Clinical Investigation* **124**(5), 1872–79.
- 3255 Moffett, A., and C. Loke. (2006). Immunology of Placentation in Eutherian Mammals. *Nature*
3256 *Reviews Immunology* **6**(8), 584–94.
- 3257 Moffett-King, A. (2002). Natural Killer Cells and Pregnancy. *Nature Reviews Immunology* **2**(9):
3258 656–63.
- 3259 Mold, J. E., and J. M. McCune. (2011). At the Crossroads between Tolerance and Aggression
3260 Revisiting the ‘Layered Immune System’ Hypothesis. *Chimerism* **2**(2), 35–41.

- 3261 Mold, J. E., J. Michaëlsson, T. D. Burt, M. O. Muench, K. P. Beckerman, M. P. Busch, T. H.
3262 Lee, D. F. Nixon, and J. M. McCune. (2008). Maternal Alloantigens Promote the
3263 Development of Tolerogenic Fetal Regulatory T Cells in Utero. *Science* **322**(5907),1562–
3264 65.
- 3265 Mold, J. E., S. Venkatasubrahmanyam, T. D. Burt, J. Michaëlsson, J. M. Rivera, S. A. Galkina,
3266 K. Weinberg, C. A. Stoddart, and J. M. McCune. (2010). Fetal and Adult Hematopoietic
3267 Stem Cells Give Rise to Distinct T Cell Lineages in Humans. *Science* **330**, 1695–1700.
- 3268 Mor, G., I. Cardenas, V. Abrahams, and S. Guller. (2011). Inflammation and Pregnancy: The
3269 Role of the Immune System at the Implantation Site. *Annals of the New York Academy of*
3270 *Sciences* **1221**(1), 80–87.
- 3271 Morales, P., J. Ricardo, J. Paganini, and P. Pontarotti. (2017). Convergent Evolution of the
3272 Adaptive Immune Response in Jawed Vertebrates and Cyclostomes: An Evolutionary
3273 Biology Approach Based Study. *Developmental and Comparative Immunology* **75**, 120–26.
- 3274 Moreau, P., F. Adrian-Cabestre, C. Menier, V. Guiard, L. Gourand, J. Dausset, E. D. Carosella,
3275 and P. Paul. (1999). IL-10 Selectively Induces HLA-G Expression in Human Trophoblasts
3276 and Monocytes. *International Immunology* **11**(5), 803–11.
- 3277 Mossman, H. W. (1987). *Vertebrate Fetal Membranes: Comparative Ontogeny and Morphology,*
3278 *Evolution, Phylogenetic Significance, Basic Functions, Research Opportunities.* United
3279 States, Rutgers University Press.
- 3280 Mossman, H. W. (1991). Classics Revisited: Comparative Morphogenesis of the Fetal
3281 Membranes and Accessory Uterine Structures. *Placenta* **12**(1), 1-5.

- 3282 Motani, R., D-y. Jian, A. Tintori, O. Rieppel, G-b. Chen. (2014). Terrestrial Origin of Viviparity
3283 in Mesozoic Marine Reptiles Indicated by Early Triassic Embryonic Fossils. *PloS ONE*
3284 **9**(2).
- 3285 Mueller, A., J. Siemer, S. Schreiner, H. Koesztner, I. Hoffmann, H. Binder, M. W. Beckmann,
3286 and R. Dittrich. (2006). Role of Estrogen and Progesterone in the Regulation of Uterine
3287 Peristalsis: Results from Perfused Non-Pregnant Swine Uteri. *Human Reproduction* **21**(7),
3288 1863–68.
- 3289 Müller, V., R. J. de Boer, S. Bonhoeffer, and E. Szathmáry. (2018). An Evolutionary Perspective
3290 on the Systems of Adaptive Immunity. *Biological Reviews* **93**(1), 505–28.
- 3291 Mundkur, R., and H. B. Devaraj Sarkar. (1982). Localization of Some Enzymes Involved in
3292 Steroid Metabolism in the Oviduct of the Skink, *Mabuya carinata*. *Current Science* **51**(5),
3293 254–55.
- 3294 Munoz-Suano, A., A. B. Hamilton, and A. G. Betz. (2011). Gimme Shelter: The Immune System
3295 during Pregnancy. *Immunological Reviews* **241**(1), 20–38.
- 3296 Murphy, B. F., M. C. Brandley, C. R. Murphy, and M. B. Thompson. (2012). Morphology and
3297 Development of the Placentae in *Eulamprus quoyii* Group Skinks (Squamata: Scincidae).
3298 *Journal of Anatomy* **220**(5), 454–71.
- 3299 Murphy, B. F., S. L. Parker, C. R. Murphy, and M. B. Thompson. (2010). Angiogenesis of the
3300 Uterus and Chorioallantois in the Eastern Water Skink *Eulamprus quoyii*. *Journal of*
3301 *Experimental Biology* **213**(19), 3340–47.

- 3302 Murphy, B. F., and M. B. Thompson. (2011). A Review of the Evolution of Viviparity in
3303 Squamate Reptiles: The Past, Present and Future Role of Molecular Biology and Genomics.
3304 *Journal of Comparative Physiology B: Biochemical, Systemic, and Environmental*
3305 *Physiology* **181**(5), 575–94.
- 3306 Murphy, B. F., M. B Thompson, and K. Belov. (2009). Evolution of Viviparity and the Maternal
3307 Immune System: Major Histocompatibility Complex (MHC) Class I Genes in Skinks.
3308 *Orbit: University of Sydney Undergraduate Research Journal* **1**(1).
- 3309 Muzio, M., J. Ni, P. Feng, and V. M. Dixit. (1997). IRAK (Pelle) Family Member IRAK-2 and
3310 MyD88 as Proximal Mediators of IL- 1 Signaling. *Science* **278**(5343), 1612–15.
- 3311 Narbaitz, R., S. Kacew, and L. Sitwell. (1981). Carbonic Anhydrase Activity in the Chick
3312 Embryo Chorioallantois: A Regional Distribution and Vitamin D Regulation. *Journal of*
3313 *Embryology and Experimental Morphology* **65**, 127–37.
- 3314 Neill, W. T. (1964). Viviparity in Snakes: Some Ecological and Zoogeographical Considerations.
3315 *The American Naturalist* **98**(898), 35–55.
- 3316 Nelson, J. L. (2012). The Otherness of Self: Microchimerism in Health and Disease. *Trends in*
3317 *Immunology* **33**(8), 421–27.
- 3318 Norell, M. A., J. Wiemann, M. Fabbri, C. Yu, C. A. Marsicano, A. Moore-Nall, D. J. Varricchio,
3319 D. Pol, and D. K. Zelenitsky. (2020). The first dinosaur egg was soft. *Nature* **583**, 406-410.

- 3320 Noy, E. B., M. K. Scott, S. V. H. Grommen, K. A. Robert, and B. De Groef. (2017). Molecular
3321 Cloning and Tissue Distribution of Crh and Pomc mRNA in the Fat-Tailed Dunnart
3322 (*Sminthopsis crassicaudata*), an Australian Marsupial. *Gene* **627**, 26–31.
- 3323 Nys, Y., J. Zawadzki, J. Gautron, and A. D. Mills. (1991). Whitening of Brown-Shelled Eggs:
3324 Mineral Composition of Uterine Fluid and Rate of Protoporphyrin Deposition. *Poultry*
3325 *Science* **70**(5), 1236–45.
- 3326 Nys, Y., J. Gautron, J. M. Garcia-Ruiz, and M. T. Hincke. (2004). Avian Eggshell
3327 Mineralization: Biochemical and Functional Characterization of Matrix Proteins. *Comptes*
3328 *Rendus - Palevol* **3**(6-7), 549–62.
- 3329 Olson, D. M., and F. Hertelendy. (1983). Avian Shell Gland Contractility: Interaction of PGF₂
3330 Alpha and Arginine Vasotocin with Ca²⁺. *The American Journal of Physiology* **244**(3), 50–
3331 57.
- 3332 Olson, D. M., K. Shimada, and R. J. Etches. (1986). Prostaglandin Concentrations in Peripheral
3333 Plasma and Ovarian and Uterine Plasma and Tissue in Relation to Oviposition in Hens.
3334 *Biology of Reproduction* **35**(5), 1140–46.
- 3335 Olson, D. M. (2003). The Role of Prostaglandins in the Initiation of Parturition. *Best Practice &*
3336 *Research Clinical Obstetrics & Gynaecology* **17**(5), 717–30.
- 3337 Opazo, J. C., F. G. Hoffmann, and J. F. Storz. (2008). Genomic Evidence for Independent
3338 Origins of β -like Globin Genes in Monotremes and Therian Mammals. *Proceedings of the*
3339 *National Academy of Sciences* **105**(5), 1590–95.

- 3340 Origgi, F. C., P. A. Klein, K. Mathes, S. Blahak, R. E. Marschang, S. J. Tucker, and E. R.
3341 Jacobson. (2001). Enzyme-Linked Immunosorbent Assay for Detecting Herpesvirus
3342 Exposure in Mediterranean Tortoises (Spur-Thighed Tortoise [*Testudo graeca*] and
3343 Hermann's Tortoise [*Testudo hermanni*]). *Journal of Clinical Microbiology* **39**(9), 3156–63.
- 3344 Ortega Brown, E., S. A. Sundstrom, B. S. Komm, Z. Yi, C. Teuscher, and C. R. Lyttle. (1990).
3345 Progesterone Regulation of Estradiol-Induced Rat Uterine Secretory Protein, Complement
3346 C3. *Biology of Reproduction* **42**(4), 713–19.
- 3347 Ostrovsky, A. N. (2013). From Incipient to Substantial: Evolution of Placentotrophy in a Phylum
3348 of Aquatic Colonial Invertebrates. *Evolution* **67**(5), 1368–82.
- 3349 Ott, T. L., M. M. Kamat, S. Vasudevan, D. H. Townson, and J. L. Pate. (2014). Maternal
3350 Immune Responses to Conceptus Signals during Early Pregnancy in Ruminants. *Animal*
3351 *Reproduction* **11**(3), 237–45.
- 3352 Owen, R. D. (1945). Immunogenetic Consequences of Vascular Anastomoses between Bovine
3353 Twins. *Science* **102**(2651), 400–401.
- 3354 Packard, G. C., C. R. Tracy, and J. J. Roth. (1977). The Physiological Ecology of Reptilian Eggs
3355 and Embryos, and the Evolution of Viviparity within the Class Reptilia. *Biological Reviews*
3356 *of the Cambridge Philosophical Society* **52**(1), 71–105.
- 3357 Packard, G. C. (1991). Physiological and Ecological Importance of Water to Embryos of
3358 Oviparous Reptiles. In D. C. Deeming, M. W. J Ferguson (Eds.), *Egg Incubation: Its Effects*
3359 *on Embryonic Development in Birds and Reptiles*. (pp. 213-228). Cambridge: Cambridge
3360 University Press.

- 3361 Packard, G. C., and M. J. Packard. (1980). Evolution of the Cleidoic Egg among Reptilian
3362 Antecedents of Birds. *Integrative and Comparative Biology* **20**(2), 351–62.
- 3363 Packard, M. J. (1994). Patterns of Mobilization and Deposition of Calcium in Embryos of
3364 Oviparous, Amniotic Vertebrates. *Israel Journal of Zoology* **40**(3–4), 481–92.
- 3365 Packard, M. J., and L. D. Lohmiller. (2002). Mineral Status of Embryos of Domestic Fowl
3366 Following Exposure in Vivo to the Carbonic Anhydrase Inhibitor Acetazolamide.
3367 *Comparative Biochemistry and Physiology - A Molecular and Integrative Physiology*
3368 **132**(2), 257–65.
- 3369 Packard, M. J., and V. G. DeMarco. (1991). Eggshell Structure and Formation in Eggs of
3370 Oviparous Reptiles. In D. C. Deeming, M. W. J Ferguson (Eds.), *Egg Incubation: Its Effects*
3371 *on Embryonic Development in Birds and Reptiles*. (pp. 53-69). Cambridge: Cambridge
3372 University Press.
- 3373 Packard, M. J., and G. C. Packard. (1984). Comparative Aspects of Calcium Metabolism in
3374 Embryonic Reptiles and Birds. *Respiration and Metabolism of Embryonic Vertebrates*,
3375 155–79.
- 3376 Packard, M. J., G. C. Packard, J. D. Miller, M. E. Jones, and W. H. N. Gutzke. (1985). Calcium
3377 Mobilization, Water Balance, and Growth in Embryos of the Agamid Lizard *Amphibolurus*
3378 *barbatus*. *Journal of Experimental Zoology* **235**(3), 349–57.
- 3379 Palmer, B. D., V. G. Demarco, and L. J. Guillette. (1993). Oviductal Morphology and Eggshell
3380 Formation in the Lizard, *Sceloporus woodi*. *Journal of Morphology* **217**(2), 205–17.

- 3381 Park, J. S., C. W. Park, C. J. Lockwood, and E. R. Norwitz. (2005). Role of Cytokines in Preterm
3382 Labor and Birth. *Minerva Ginecologica* **57**(4), 349–66.
- 3383 Parker, S. L., and R. M. Andrews. (2006). Evolution of Viviparity in Sceloporine Lizards: In
3384 Utero Po₂ as a Developmental Constraint during Egg Retention. *Physiological and*
3385 *Biochemical Zoology* **79**(3), 581–92.
- 3386 Parker, S. L., F. Manconi, C. R. Murphy, and M. B. Thompson. (2010). Uterine and Placental
3387 Angiogenesis in the Australian Skinks, *Ctenotus taeniolatus*, and *Saiphos equalis*.
3388 *Anatomical Record* **293**(5), 829–38.
- 3389 Pashen, R. L., and W. R. Allen. (1979). The Role of the Fetal Gonads and Placenta in Steroid
3390 Production, Maintenance of Pregnancy and Parturition in the Mare. *Journal of*
3391 *Reproduction and Fertility* **27**, 499.
- 3392 Paulesu, L., R. Romagnoli, M. Marchetti, M. Cintorino, P. Ghiara, F. M. Guarino, and G. Ghiara.
3393 (1995). Cytokines in the Viviparous Reproduction of Squamate Reptiles: Interleukin-1 α
3394 (IL-1 α) and IL-1 β in Placental Structures of a Skink. *Placenta* **16**(2), 193–205.
- 3395 Paulesu, L. (1997). Cytokines in Mammalian Reproduction and Speculation about Their Possible
3396 Involvement in Nonmammalian Viviparity. *Microscopy Research and Technique* **38**(1-2),
3397 188–94.
- 3398 Paulesu, L., E. Bigliardi, E. Paccagnini, F. Ietta, C. Cateni, C. P. Guillaume, and B. Heulin.
3399 (2005). Cytokines in the Oviparity/Viviparity Transition: Evidence of the Interleukin-1
3400 System in a Species with Reproductive Bimodality, the Lizard *Lacerta vivipara*. *Evolution*
3401 *and Development* **7**(4), 282–88.

- 3402 Paulesu, L., S. Jantra, F. Ietta, R. Brizzi, and E. Bigliardi. (2008). Interleukin-1 in Reproductive
3403 Strategies. *Evolution and Development* **10**(6), 778–88.
- 3404 Paulesu, L., R. Romagnoli, and E. Bigliardi. (2005). Materno-Fetal Immunotolerance: Is
3405 Interleukin-1 a Fundamental Mediator in Placental Viviparity? *Developmental and*
3406 *Comparative Immunology* **29**(5), 409–15.
- 3407 Peck, A., and E. D. Mellins. (2010). Plasticity of T-Cell Phenotype and Function: The T Helper
3408 Type 17 Example. *Immunology* **129**(2), 147–53.
- 3409 Petersdorf, E. W., T. A. Gooley, M. Malkki, A. P. Bacigalupo, A. Cesbron, E. Du Toit, G.
3410 Ehninger, et al. (2014). HLA-C Expression Levels Define Permissible Mismatches in
3411 Hematopoietic Cell Transplantation. *Blood* **124**(26), 3996–4003.
- 3412 Petraglia, F., G. C. Garuti, B. De Ramundo, S. Angioni, A. R. Genazzani, and L. M. Bilezikjian.
3413 (1990). Mechanism of Action of Interleukin-1 β in Increasing Corticotropin-Releasing
3414 Factor and Adrenocorticotropin Hormone Release from Cultured Human Placental Cells.
3415 *American Journal of Obstetrics and Gynecology* **163**(4), 1307–12.
- 3416 Picariello, O., G. Ciarcia, and F. Angelini. (1989). The Annual Cycle of Oviduct in *Tarentola m.*
3417 *mauritanica* (Reptilia Gekkonidae). *Amphibia-Reptilia* **10**, 371–86.
- 3418 **Pincheira-Donoso, D., Jara, M., Reaney, A., García-Roa, R., Saldarriaga-Córdoba, M., and**
3419 **Hodgson, D. J.** (2017). Hypoxia and hypothermia as rival agents of selection driving the
3420 evolution of viviparity in lizards. *Global Ecology and Biogeography* **26**, 1238–1246.

- 3421 Piñeiro, G., Ferigolo, J., Meneghel, M. and Laurin, M. (2012). The oldest known amniotic
3422 embryos suggest viviparity in mesosaurs. *Historical Biology*, **24**(6), 620-630.
- 3423 Pines, M., V. Knopov, and A. Bar. (1995). Involvement of Osteopontin in Egg Shell Formation
3424 in the Laying Chicken. *Matrix Biology* **14**(9), 765–71.
- 3425 Podhalicz-Dzięgielewska, M., T. Rotkiewicz, T. Janowski, S. Zduńczyk, and A. Raś. (2000).
3426 Histological Findings in Placentomes of Cows with Retained Placenta. *Medycyna*
3427 *Weterynaryjna* **56**(6), 392–94.
- 3428 Pough, F. H. (1980). Blood Oxygen Transport and Delivery in Reptiles. *Integrative and*
3429 *Comparative Biology* **20**(1), 173–85.
- 3430 Pradeu, T., E. Vitanza (2011). Critique of the Self-Nonsel Theory. In E. Vitanza (Eds.), *The*
3431 *Limits of the Self: Immunology and Biological Identity*. (pp. 85-130). Oxford University
3432 Press.
- 3433 Putnam, C. D., D. W. Brann, R. C. Kolbeck, and V. B. Mahesh. (1991). Inhibition of Uterine
3434 Contractility by Progesterone and Progesterone Metabolites: Mediation by Progesterone and
3435 Gamma Amino Butyric Acid(A) Receptor Systems. *Biology of Reproduction* **45**(2), 266–72.
- 3436 Pye, G. W., D. R. Brown, M. F. Nogueira, K. A. Vliet, T. R. Schoeb, E. R. Jacobson, and R. A.
3437 Bennett. (2001). Experimental Inoculation of Broad-Nosed Caimans (*Caiman latirostris*)
3438 and Siamese Crocodiles (*Crocodylus siamensis*) with *Mycoplasma alligatoris*. *Journal of*
3439 *Zoo and Wildlife Medicine* **32**(2), 196–201.

- 3440 **Pyron, R. A. 2015. Advancing perspectives on parity-mode evolution. *Journal of***
3441 *Experimental Zoology (Molecular and Developmental Evolution)* 324(6), 562–563.
- 3442 Pyron, R. A., and F. T. Burbrink. (2014). Early Origin of Viviparity and Multiple Reversions to
3443 Oviparity in Squamate Reptiles. *Ecology Letters* **17**(1), 13–21.
- 3444 Qualls, C. P. (1996). Influence of the Evolution of Viviparity on Eggshell Morphology in the
3445 Lizard, *Lerista bougainvillii*. *Journal of Morphology* **228**(2), 119–25.
- 3446 Rajagopalan, S., Y. T. Bryceson, S. P. Kuppusamy, D. E. Geraghty, A. van der Meer, I. Joosten,
3447 and E. O. Long. (2006). Activation of NK Cells by an Endocytosed Receptor for Soluble
3448 HLA-G. *PLoS Biology* **4**(1).
- 3449 Rajagopalan, S., and E. O. Long. (2012). KIR2DL4 (CD158d): An Activation Receptor for
3450 HLA-G. *Frontiers in Immunology* **3**, 1–6.
- 3451 Ramírez-Pinilla, M. P. (2006). Placental Transfer of Nutrients during Gestation in an Andean
3452 Population of the Highly Matrotrophic Lizard Genus *Mabuya* (Squamata: Scincidae).
3453 *Herpetological Monographs* **20**, 194–204.
- 3454 Ramírez-Pinilla, M. P., E. D. Rueda, and E. Stashenko. (2011). Transplacental Nutrient Transfer
3455 during Gestation in the Andean Lizard *Mabuya Sp.* (Squamata, Scincidae). *Journal of*
3456 *Comparative Physiology B: Biochemical, Systemic, and Environmental Physiology* **181**(2),
3457 249–68.
- 3458 Ramsay, T. G., J. Karousis, M. E. White, and C. K. Wolverton. (1991). Fatty Acid Metabolism
3459 by the Porcine Placenta. *Journal of Animal Science* **69**(9), 3645–54.

- 3460 Ramsdell, F., and A. Y. Rudensky. (2020). Foxp3: A Genetic Foundation for Regulatory T Cell
3461 Differentiation and Function. *Nature Immunology* **21**(7), 708–9.
- 3462 **Rao, A., Fernández, M. S., Cölfen, H., & Arias, J. L.** (2015). Distinct effects of avian egg
3463 derived anionic proteoglycans on the early stages of calcium carbonate
3464 mineralization. *Crystal Growth & Design* **15**(5), 2052-2056.
- 3465 Rapacz-Leonard, A., M. Leonard, M. Chmielewska-Krzesińska, K. Paździor-Czapula, and T.
3466 Janowski. (2018). Major Histocompatibility Complex Class I in the Horse (*Equus caballus*)
3467 Placenta during Pregnancy and Parturition. *Placenta* **74**, 36–46.
- 3468 Ravanos, K., T. Dagklis, S. Petousis, C. Margioulas-Siarkou, Y. Prapas, and N. Prapas. (2015).
3469 Factors Implicated in the Initiation of Human Parturition in Term and Preterm Labor: A
3470 Review. *Gynecological Endocrinology* **31**(9), 679–83.
- 3471 Rawn, S. M., and J. C. Cross. (2008). The Evolution, Regulation, and Function of Placenta-
3472 Specific Genes. *Annual Review of Cell and Developmental Biology* **24**, 159–81.
- 3473 Rebmann, V., A. Busemann, M. Lindemann, and H. Grosse-Wilde. (2003). Detection of HLA-
3474 G5 Secreting Cells. *Human Immunology* **64**(11), 1017–24.
- 3475 Rebmann, V., F. Da Silva Nardi, B. Wagner, and P. A. Horn. (2014). HLA-G as a Tolerogenic
3476 Molecule in Transplantation and Pregnancy. *Journal of Immunology Research*. **2014**,
3477 297073.

3478 Recknagel H, and K.R. Elmer. Differential reproductive investment in co-occurring oviparous
3479 and viviparous common lizards (*Zootoca vivipara*) and implications for life-history trade-
3480 offs with viviparity (2019). *Oecologia* **190**(1), 85-98.

3481 Recknagel, H., M. Carruthers, A. A. Yurchenko, M. Nokhbatolfoghahai, N. A. Kamenos, M. M.
3482 Bain, and K. R. Elmer. (2021a). The Functional Genetic Architecture of Egg-Laying and
3483 Live-Bearing Reproduction in Common Lizards. *Nature Ecology & Evolution*. **5**, 1546–
3484 1556

3485 **Recknagel, H., N.A. Kamenos, and K.R. Elmer.** (2021b). Evolutionary origins of viviparity
3486 consistent with palaeoclimate and lineage diversification. *Journal of Evolutionary Biology*
3487 **34**, 1167–1176.

3488 Recknagel, H., N. A. Kamenos, and K. R. Elmer. (2018). Common Lizards Break Dollo’s Law
3489 of Irreversibility: Genome-Wide Phylogenomics Support a Single Origin of Viviparity and
3490 Re-Evolution of Oviparity. *Molecular Phylogenetics and Evolution* **127**, 579–88.

3491 Reiber, M. A., and D. E. Conner. (1995). Effect of Mating Activity on the Ability of Salmonella
3492 Enteritidis to Persist in the Ovary and Oviduct of Chickens. *Avian Diseases*. **39**(2), 323–27.

3493 Reiber, M. A., D. E. Conner, and S. F. Bilgili. (1995). Salmonella Colonization and Shedding
3494 Patterns of Hens Inoculated via Semen. *Avian Diseases*. **39**(2), 317–22.

3495 Reynolds, L. P., J. S. Caton, D. A. Redmer, A. T. Grazul-Bilska, K. A. Vonnahme, P. P.
3496 Borowicz, J. S. Luther, J. M. Wallace, G. Wu, and T. E. Spencer. 2006. Evidence for
3497 Altered Placental Blood Flow and Vascularity in Compromised Pregnancies. *Journal of*
3498 *Physiology* **572**(1), 51–58.

- 3499 Ribatti, D. 2015. Peter Brian Medawar and the Discovery of Acquired Immunological Tolerance.
3500 *Immunology Letters* **167**(2), 63–66.
- 3501 Ribatti, D., A. Frigeri, B. Nico, G. P. Nicchia, M. De Giorgis, L. Roncali, and M. Svelto. (2002).
3502 Aquaporin-1 Expression in the Chick Embryo Chorioallantoic Membrane. *Anatomical*
3503 *Record* **268**(2), 85–89.
- 3504 Rieger, L. (2002). Th1- and Th2-like Cytokine Production by First Trimester Decidual Large
3505 Granular Lymphocytes Is Influenced by HLA-G and HLA-E. *Molecular Human*
3506 *Reproduction* **8**(3), 255–61.
- 3507 Rimer, J., I. R. Cohen, and N. Friedman. (2014). Do All Creatures Possess an Acquired Immune
3508 System of Some Sort? *BioEssays* **36**(3), 273–81.
- 3509 Risau, W. (1997). Mechanisms of Angiogenesis. *Nature* **386**.
- 3510 Roberts, C. T., and W. G. Breed. (1996). Variation in Ultrastructure of Muroid Coat and Shell
3511 Membrane Secretion of a Dasyurid Marsupial. *Reproduction, Fertility and Development* **8**
3512 (4), 645–48.
- 3513 Roberts, C. T., W. G. Breed, and G. Mayrhofer. (1994). Origin of the Oocyte Shell Membrane of
3514 a Dasyurid Marsupial: An Immunohistochemical Study. *Journal of Experimental Zoology*
3515 **270**(3), 321–31.
- 3516 Roberts, C. T., and W. G. Breed. (1994). Placentation in the Dasyurid Marsupial, *Sminthopsis*
3517 *Crassicaudata*, the Fat-Tailed Dunnart, and Notes on Placentation of the Didelphid,
3518 Placentation in the Dasyurid Marsupial, *Sminthopsis crassicaudata*, the Fat-Tailed Dunnart,

- 3519 and Notes on placentation of the didelphid, *Monodelphis domestica*. *Journal of*
3520 *Reproduction and Fertility* **100**, 105–13.
- 3521 Robinson, B. G., J. L. Arbiser, R. L. Emanuel, and J. A. Majzoub. (1989). Species-Specific
3522 Placental Corticotropin Releasing Hormone Messenger RNA and Peptide Expression.
3523 *Molecular and Cellular Endocrinology* **62**(2), 337–41.
- 3524 Rodriguez-Martinez, H., F. Saravia, M. Wallgren, E. A. Martinez, L. Sanz, J. Roca, J. M.
3525 Vazquez, and J. J. Calvete. (2010). Spermadhesin PSP-I/PSP-II Heterodimer Induces
3526 Migration of Polymorphonuclear Neutrophils into the Uterine Cavity of the Sow. *Journal of*
3527 *Reproductive Immunology* **84**(1), 57–65.
- 3528 Rodríguez-Navarro, A. B., P. Marie, Y. Nys, M. T. Hincke, and J. Gautron. (2015). Amorphous
3529 Calcium Carbonate Controls Avian Eggshell Mineralization: A New Paradigm for
3530 Understanding Rapid Eggshell Calcification. *Journal of Structural Biology* **190**(3), 291–
3531 303.
- 3532 Romagnoli, R., C. Cateni, F. M. Guarino, E. Bigliardi, and L. R. Paulesu. (2003). Potential Role
3533 of Interleukin-1 at the Peri-Ovulation Stage in a Species of Placental Viviparous Reptile, the
3534 Three-Toed Skink, *Chalcides chalcides* (Squamata: Scincidae). *Reproductive Biology and*
3535 *Endocrinology* **1**, 1–6.
- 3536 Romer, A. S. (1957). Origin of the amniote egg. *The Scientific Monthly* **85**, 57–63.
- 3537 Romero, R., D. T. Brody, E. Oyarzun, M. Mazor, Y. K. Wu, J. C. Hobbins, and S. K. Durum.
3538 (1989). Infection and Labor: III. Interleukin-1: A Signal for the Onset of Parturition.
3539 *American Journal of Obstetrics and Gynecology* **160**(5), 1117–23.

- 3540 Romero, R., M. Mazor, F. Brandt, W. Sepulveda, C. Avila, D. B. Cotton, and C. A. Dinarello.
3541 (1992). Interleukin-1 α and Interleukin-1 β in Preterm and Term Human Parturition.
3542 *American Journal of Reproductive Immunology* **27**(3-4), 117–23.
- 3543 Rose-Martel, M., J. Du, and M. T. Hincke. (2012). Proteomic Analysis Provides New Insight
3544 into the Chicken Eggshell Cuticle. *Journal of Proteomics* **75**(9), 2697–2706.
- 3545 Ross, G. T. (1979). Human Chorionic Gonadotropin and Maternal Recognition of Pregnancy.
3546 *Maternal Recognition of Pregnancy* **64**.
- 3547 Rothchild, I. (2003). The Yolkless Egg and the Evolution of Eutherian Viviparity. *Biology of*
3548 *Reproduction* **68**(2), 337–57.
- 3549 Rothwell, L., J. R. Young, R. Zoorob, C. A. Whittaker, P. Hesketh, A. Archer, A. L. Smith, and
3550 P. Kaiser. (2004). Cloning and Characterization of Chicken IL-10 and Its Role in the
3551 Immune Response to *Eimeria Maxima*. *The Journal of Immunology* **173**(4), 2675–82.
- 3552 Rouas-Freiss, N., R. M. Gonçalves, C. Menier, J. Dausset, and E. D. Carosella. (1997). Direct
3553 Evidence to Support the Role of HLA-G in Protecting the Fetus from Maternal Uterine
3554 Natural Killer Cytolysis. *Proceedings of the National Academy of Sciences* **94**(21), 11520–
3555 25.
- 3556 Roussev, R. G., B. Acacio, S. C. Ng, and C. B. Coulam. (2008). Duration of Intralipid’s
3557 Suppressive Effect on NK Cell’s Functional Activity. *American Journal of Reproductive*
3558 *Immunology* **60**(3), 258–63.

- 3559 Rowe, J. H., J. M. Ertelt, L. Xin, and S. S. Way. (2012). Pregnancy Imprints Regulatory Memory
 3560 That Sustains Anergy to Fetal Antigen. *Nature* **490**(7418), 102–6.
- 3561 Rzasas, J. (1978). Effects of Arginine Vasotocin and Prostaglandin E1 on the Hen Uterus.
 3562 *Prostaglandins* **16**(3), 357–72.
- 3563 Saad, A. H., and S. El Deeb. (1990). Immunological Changes during Pregnancy in the
 3564 Viviparous Lizard, *Chalcides ocellatus*. *Veterinary Immunology and Immunopathology*
 3565 **25**(3): 279–86.
- 3566 Saito, S., A. Nakashima, T. Shima, and M. Ito. (2010). Th1/Th2/Th17 and Regulatory T-Cell
 3567 Paradigm in Pregnancy. *American Journal of Reproductive Immunology* **63**(6), 601–10.
- 3568 Samuel, C. A., and J. S. Perry. (1972). The Ultrastructure of Pig Trophoblast Transplanted to an
 3569 Ectopic Site in the Uterine Wall. *Journal of Anatomy* **113**(Pt 1), 139.
- 3570 Sarkar, S., N. K. Sarkar, and B. R. Maiti. (1995). Histological and Functional Changes of
 3571 Oviductal Endometrium during Seasonal Reproductive Cycle of the Soft-shelled Turtle,
 3572 *Lissemys punctata punctata*. *Journal of Morphology* **224**(1), 1–14.
- 3573 Satterfield, M. C., K. A. Dunlap, K. Hayashi, R. C. Burghardt, T. E. Spencer, and F. W. Bazer.
 3574 (2007). Tight and Adherens Junctions in the Ovine Uterus: Differential Regulation by
 3575 Pregnancy and Progesterone. *Endocrinology* **148**(8), 3922–31.
- 3576 Schiffman, J. S., and P. L. Ralph. (2022). System Drift and Speciation. *Evolution* **76** (2), 236–51.

- 3577 Schjenken, J. E., and S. A. Robertson. (2014). Seminal Fluid and Immune Adaptation for
3578 Pregnancy - Comparative Biology in Mammalian Species. *Reproduction in Domestic*
3579 *Animals* **49**, 27–36.
- 3580 Schumacher, A., and Zenclussen, A. C. (2015). The Paternal Contribution to Fetal Tolerance.
3581 *Advances in experimental medicine and biology* **868**, 211–225.
- 3582 Schwaha, T., M. Moosbrugger, M. Walzl, and A. N. Ostrovsky. (2019). First Ultrastructural
3583 Evidence of Placental Nutrition in a Ctenostome Bryozoan: Example of *Amathia*
3584 *verticillata*. *Zoomorphology* **138**(2), 221–32.
- 3585 Seavey, M., and T. R. Mosmann. (2006). Paternal Antigen-Bearing Cells Transferred during
3586 Insemination Do Not Stimulate Anti-Paternal CD8 + T Cells: Role of Estradiol in Locally
3587 Inhibiting CD8 + T Cell Responses. *The Journal of Immunology* **177**(11), 7567–78.
- 3588 Sellens, M. H., E. J. Jenkinson, and W. D. Billington. (1978). Major Histocompatibility Complex
3589 and Non-Major Histocompatibility Complex Antigens on Mouse Ectoplacental Cone and
3590 Placental Trophoblastic Cells. *Transplantation* **25**(4), 173–79.
- 3591 Shadrix, C. A., D. R. Crotzer, S. L. McKinney, and J. R. Stewart. (1994). Embryonic Growth and
3592 Calcium Mobilization in Oviposited Eggs of the Scincid Lizard, *Eumeces fasciatus*. *Copeia*
3593 **2**, 493.
- 3594 Shaw, G., and M. B. Renfree. (2001). Fetal Control of Parturition in Marsupials. *Reproduction,*
3595 *Fertility and Development* **13**(8), 653–59.

- 3596 Shen, X. X., D. Liang, J. Z. Wen, and P. Zhang. (2011). Multiple Genome Alignments Facilitate
3597 Development of NPCL Markers: A Case Study of Tetrapod Phylogeny Focusing on the
3598 Position of Turtles. *Molecular Biology and Evolution* **28**(12), 3237–52.
- 3599 Shine, R. (1983). Reptilian Viviparity in Cold Climates: Testing the Assumptions of an
3600 Evolutionary Hypothesis. *Oecologia* **57**(3), 397–405.
- 3601 Shine, R., and J. J. Bull. (1979). The Evolution of Live-Bearing in Lizards and Snakes. *The*
3602 *American Naturalist* **113**(6), 905–23.
- 3603 Shine, R., and L. J. Guillette. (1988). The Evolution of Viviparity in Reptiles: A Physiological
3604 Model and Its Ecological Consequences. *Journal of Theoretical Biology* **132**(1), 43–50.
- 3605 Shine, R., and M. B. Thompson. (2006). Did Embryonic Responses to Incubation Conditions
3606 Drive the Evolution of Reproductive Modes in Squamate Reptiles. *Herpetological*
3607 *Monographs* **20**(2006), 186–93.
- 3608 Shynlova, O., P. Tsui, A. Dorogin, and S. J. Lye. (2008). Monocyte Chemoattractant Protein-1
3609 (CCL-2) Integrates Mechanical and Endocrine Signals That Mediate Term and Preterm
3610 Labor. *The Journal of Immunology* **181**(2), 1470–79.
- 3611 Simkiss, K. (1980). Water and Ionic Fluxes inside the Egg. *Integrative and Comparative Biology*
3612 **20**(2), 385–93.
- 3613 Simmonds, C. S., G. Karsenty, A. C. Karaplis, and C. S. Kovacs. (2010). Parathyroid Hormone
3614 Regulates Fetal-Placental Mineral Homeostasis. *Journal of Bone and Mineral Research*
3615 **25**(3), 594–605.

- 3616 Sipes, S. L., M. V. Medaglia, D. L. Stabley, C. S. DeBruyn, M. S. Alden, V. Catenacci, and C. P.
3617 Landel. (1996). A New Major Histocompatibility Complex Class Ib Gene Expressed in the
3618 Mouse Blastocyst and Placenta. *Immunogenetics* **45**(2), 108–20.
- 3619 Sites, J. W., T. W. Reeder, and J. J. Wiens. (2011). Phylogenetic Insights on Evolutionary
3620 Novelties in Lizards and Snakes: Sex, Birth, Bodies, Niches, and Venom. *Annual Review of*
3621 *Ecology, Evolution, and Systematics* **42**(1), 227–44.
- 3622 Slater, D., W. Dennes, R. Sawdy, V. Allport, and P. Bennett. (1999). Expression of Cyclo-
3623 Oxygenase Types-1 and-2 in Human Fetal Membranes throughout Pregnancy. *Journal of*
3624 *Molecular Endocrinology* **22**(2), 125–30.
- 3625 Slater, D. M., L. C. Berger, R. Newton, G. E. Moore, and P. R. Bennett. (1995). Expression of
3626 Cyclooxygenase Types 1 and 2 in Human Fetal Membranes at Term. *American Journal of*
3627 *Obstetrics and Gynecology* **172**, 77–82.
- 3628 Slater, M., and C. R. Murphy. (1999). Thrombospondin Is Sequentially Expressed and Then De-
3629 Expressed during Early Pregnancy in the Rat Uterus. *Histochemical Journal* **31**(7), 471–75.
- 3630 **Smith, H. M. (1975) Grist for the mills of herpetophiles in Mexico. *Bulletin of the Maryland***
3631 *Herpetological Society* **11**, 40-44.
- 3632 Smith, S. A., C. Austin, and R. Shine. (2001). A Phylogenetic Analysis of Variation in
3633 Reproductive Mode within an Australian Lizard (*Saiphos equalis*, Scincidae). *Biological*
3634 *Journal of the Linnean Society* **74**, 131-139.

- 3635 Soloff, M. S., Y. J. Jeng, M. G. Izban, M. Sinha, B. A. Luxon, S. J. Stammes, and S. K. England.
3636 (2011). Effects of Progesterone Treatment on Expression of Genes Involved in Uterine
3637 Quiescence. *Reproductive Sciences* **18**(8), 781–97.
- 3638 Song, G., D. W. Bailey, K. A. Dunlap, R. C. Burghardt, T. E. Spencer, F. W. Bazer, and G. A.
3639 Johnson. (2010). Cathepsin B, Cathepsin L, and Cystatin C in the Porcine Uterus and
3640 Placenta: Potential Roles in Endometrial/Placental Remodeling and in Fluid-Phase
3641 Transport of Proteins Secreted by Uterine Epithelia across Placental Areolae. *Biology of*
3642 *Reproduction* **82**(5), 854–64.
- 3643 Sooranna, S. R., Y. Lee, L. U. Kim, A. R. Mohan, P. R. Bennett, and Mark R. Johnson. (2004).
3644 Mechanical Stretch Activates Type 2 Cyclooxygenase via Activator Protein-1 Transcription
3645 Factor in Human Myometrial Cells. *Molecular Human Reproduction* **10**(2), 109–13.
- 3646 Sorbera, L., G. Giannoukos, and I. Callard. (1988). Progesterone and Relaxin Inhibit Turtle
3647 Myometrium. *American Society of Zoologists Conference Proceedings* Lawrence, KS.
- 3648 Speake, B. K., J. F. Herbert, and M. B. Thompson. (2004). Evidence for Placental Transfer of
3649 Lipids during Gestation in the Viviparous Lizard, *Pseudemoia entrecasteauxii*.
3650 *Comparative Biochemistry and Physiology - A Molecular and Integrative Physiology*
3651 **139**(2): 213–20.
- 3652 Spencer, T. E., and F. W. Bazer. (2004). Uterine and Placental Factors Regulating Conceptus
3653 Growth in Domestic Animals. *Journal of Animal Science* **82**, E4–13.
- 3654 Srivastava, M. D., J. Lippes, and B. I. Sahai Srivastava. (1996). Cytokines of the Human
3655 Reproductive Tract. *American Journal of Reproductive Immunology* **36**(3), 157–66.

- 3656 Stadtmauer, D. J., and G. P. Wagner. (2020a). Cooperative Inflammation: The Recruitment of
3657 Inflammatory Signaling in Marsupial and Eutherian Pregnancy. *Journal of Reproductive*
3658 *Immunology* **137**, 102626.
- 3659 ———. (2020b). The Primacy of Maternal Innovations to the Evolution of Embryo
3660 Implantation. *Integrative and Comparative Biology* **60**(3), 742–52.
- 3661 Starck, J. M. (2021). Morphology of the Avian Yolk Sac. *Journal of Morphology*. **282** (7), 959-
3662 972
- 3663 Staub, R., and J. Emberton. (2002). *Eryx jayakari* (Arabian Sand Boa) Reproduction.
3664 *Herpetological Review* **33**, 214.
- 3665 Stein, K., E. Prondvai, T. Huang, J-M. Baele, P. M. Sander, and R.Reisz (2019) Structure and
3666 evolutionary implications of the earliest (Sinemurian, Early Jurassic) dinosaur eggs and
3667 eggshells. *Scientific Reports* **9**, 4424.
- 3668 Stern, P. L., N. Beresford, C. I. Friedman, V. C. Stevens, J. M. Risk, and P. M. Johnson. (1987).
3669 Class I-like MHC Molecules Expressed by Baboon Placental Syncytiotrophoblast. *The*
3670 *Journal of Immunology* **138**(4), 1088–91.
- 3671 Stevens, A. M., W. M. McDonnell, M. E. Mullarkey, J. M. Pang, W. Leisenring, and J. L.
3672 Nelson. (2004). Liver Biopsies from Human Females Contain Male Hepatocytes in the
3673 Absence of Transplantation. *Laboratory Investigation* **84**(12), 1603–9.

3674 Stewart, J. R. (1989). Facultative Placentotrophy and the Evolution of Squamate Placentation:
3675 Quality of Eggs and Neonates in *Virginia striatula*. *The American Naturalist* **133**(1), 111–
3676 37.

3677 ———. (2013). Fetal Nutrition in Lecithotrophic Squamate Reptiles: Toward a Comprehensive
3678 Model for Evolution of Viviparity and Placentation. *Journal of Morphology* **274**(7), 824–
3679 43.

3680 Stewart, J. R., and M. B. Thompson. (1993). A Novel Pattern of Embryonic Nutrition in a
3681 Viviparous Reptile. *Journal of Experimental Biology* **174**(1), 97–108.

3682 Stewart, J. R., T. W. Ecy, C. P. Garland, S. P. Fregoso, E. K. Price, J. F. Herbert, and M. B.
3683 Thompson. (2009). Maternal Provision and Embryonic Uptake of Calcium in an Oviparous
3684 and a Placentotrophic Viviparous Australian Lizard (Lacertilia: Scincidae). *Comparative*
3685 *Biochemistry and Physiology. Part A, Molecular & Integrative Physiology* **153**(2), 202–8.

3686 Stewart, J. R., and R. E. Castillo. (1984). Nutritional Provision of the Yolk of Two Species of
3687 Viviparous Reptiles. *Physiological Zoology* **57**(4), 377–83.

3688 Stewart, J. R., and D. G. Blackburn. (1988). Reptilian Placentation: Structural Diversity and
3689 Terminology. *Copeia* **1988** (4), 839.

3690 Stewart, J. R., and T. W. Ecy. (2010). Patterns of Maternal Provision and Embryonic
3691 Mobilization of Calcium in Oviparous and Viviparous. *Herpetological Conservation and*
3692 *Biology* **5**(2), 341–59.

3693 Stewart, J. R., T. W. Eday, and D. G. Blackburn. (2004). Sources and Timing of Calcium
3694 Mobilization during Embryonic Development of the Corn Snake, *Pantherophis guttatus*.
3695 *Comparative Biochemistry and Physiology - A Molecular and Integrative Physiology*
3696 **139**(3), 335–41.

3697 Stewart, J. R., T. W. Eday, and B. Heulin. (2009). Calcium Provision to Oviparous and
3698 Viviparous Embryos of the Reproductively Bimodal Lizard *Lacerta (Zootoca) vivipara*.
3699 *Journal of Experimental Biology* **212**(16), 2520–24.

3700 Stewart, J. R., T. W. Eday, B. Heulin, S. P. Fregoso, and B. J. Linville. (2011). Developmental
3701 Expression of Calcium Transport Proteins in Extraembryonic Membranes of Oviparous and
3702 Viviparous *Zootoca vivipara* (Lacertilia, Lacertidae). *Journal of Experimental Biology*
3703 **214**(18), 2999–3004.

3704 Stewart, J. R., A. N. Mathieson, T. W. Eday, J. F. Herbert, S. L. Parker, and M. B. Thompson.
3705 (2010). Uterine and Eggshell Structure and Histochemistry in a Lizard with Prolonged
3706 Uterine Egg Retention (Lacertilia, Scincidae, *Saiphos*). *Journal of Morphology* **271**(11),
3707 1342–51.

3708 Stewart, J. R., and M. B. Thompson. (2009). Parallel Evolution of Placentation in Australian
3709 Scincid Lizards. *Journal of Experimental Zoology Part B: Molecular and Developmental*
3710 *Evolution* **312**(6), 590–602.

3711 Stinnett, H. K., J. R. Stewart, T. W. Eday, R. A. Pyles, J. F. Herbert, and M. B. Thompson.
3712 (2011). Placental Development and Expression of Calcium Transporting Proteins in the

- 3713 Extraembryonic Membranes of a Placentotrophic Lizard. *Journal of Morphology* **273**(3),
3714 347–59.
- 3715 Stouffer, R. L., and J. D. Hennebold. (2015). Structure, Function, and Regulation of the Corpus
3716 Luteum. In *Knobil and Neill's Physiology of Reproduction: Two-Volume Set*. (Vol. 1, pp.
3717 1023-1076). Elsevier Inc.
- 3718 Suzuki, Y., C. S. Kovacs, H. Takanaga, J. B. Peng, C. P. Landowski, and M. A. Hediger. (2008).
3719 Calcium Channel TRPV6 Is Involved in Murine Maternal-Fetal Calcium Transport. *Journal*
3720 *of Bone and Mineral Research* **23**(8), 1249–56.
- 3721 Svensson-Arvelund, J., R. B. Mehta, R. Lindau, E. Mirrasekhian, H. Rodriguez-Martinez, G.
3722 Berg, G. E. Lash, M. C. Jenmalm, and J. Ernerudh. (2021). The Human Fetal Placenta
3723 Promotes Tolerance against the Semiallogeneic Fetus by Inducing Regulatory T Cells and
3724 Homeostatic M2 Macrophages. *The Journal of Immunology* **194**(4).
- 3725 Swain, R., and S. M. Jones. (2000). Facultative Placentotrophy: Half-Way House or Strategic
3726 Solution? *Comparative Biochemistry and Physiology - A Molecular and Integrative*
3727 *Physiology* **127**(4), 441–51.
- 3728 Swain, R., and S. M. Jones. (1997). Maternal-Fetal Transfer of 3H-Labelled Leucine in the
3729 Viviparous Lizard *Niveoscincus metallicus* (Scincidae: Lygosominae). *Journal of*
3730 *Experimental Zoology* **277**(2), 139–45.
- 3731 Sykes, L., D. A. MacIntyre, T. Ghee Teoh, and P. R. Bennett. (2014). Anti-Inflammatory
3732 Prostaglandins for the Prevention of Preterm Labour. *Reproduction* **148**(2).

- 3733 Szekeres-Bartho, J., S. Šučurović, and B. Mulac-Jeričević. (2018). The Role of Extracellular
3734 Vesicles and PIBF in Embryo-Maternal Immune-Interactions. *Frontiers in Immunology* **9**,
3735 2890.
- 3736 Takahashi, T., H. Ogawa, R. Inaba, and M. Kawashima. (2004). Changes in Prostaglandin F
3737 Concentration in the Uterus (Shell Gland) of the Hen Oviduct in Relation to Oviposition
3738 and Estrogen. *Poultry Science* **83**(10), 1745–49.
- 3739 Tamizian, O., and S. Arulkumaran. (2004). Uterine Contractions. *The Management of Labour*.
3740 Orient Blackswan, **86**.
- 3741 Tartakovsky, B., and E. Ben-Yair. (1991). Cytokines Modulate Preimplantation Development
3742 and Pregnancy. *Developmental Biology* **146**(2), 345–52.
- 3743 Tayade, C., G. P. Black, Y. Fang, and A. Croy. (2006). Differential Gene Expression in
3744 Endometrium, Endometrial Lymphocytes, and Trophoblasts during Successful and Abortive
3745 Embryo Implantation. *The Journal of Immunology* **176**, 148–56.
- 3746 Teles, A., A. Schumacher, M. C. Kühnle, N. Linzke, C. Thuere, P. Reichardt, C. E. Tadokoro, G.
3747 J. Hämmerling, and A. C. Zenclussen. (2013). Control of Uterine Microenvironment by
3748 Foxp3+ Cells Facilitates Embryo Implantation. *Frontiers in Immunology* **4**, 158.
- 3749 Terzidou, V. (2007). Biochemical and Endocrinological Preparation for Parturition. *Best
3750 Practice and Research: Clinical Obstetrics and Gynaecology* **21**(5), 729–56.
- 3751 Thatcher, W. W., M. D. Meyer, and G. Danet-Desnoyers. (1995). Maternal Recognition of
3752 Pregnancy. *Journal of Reproduction and Fertility* **49**, 15–28.

- 3753 Thompson, M. B., J. R. Stewart, and B. K. Speake. (2000). Comparison of Nutrient Transport
3754 across the Placenta of Lizards Differing in Placental Complexity. *Comparative*
3755 *Biochemistry and Physiology - A Molecular and Integrative Physiology* **127**(4), 469–79.
- 3756 Thompson, M. B., J. R. Stewart, B. K. Speake, K. J. Russell, and R. J. McCartney. (1999).
3757 Placental Transfer of Nutrients during Gestation in the Viviparous Lizard, *Pseudemoia*
3758 *spenceri*. *Journal of Comparative Physiology - B Biochemical, Systemic, and*
3759 *Environmental Physiology* **169**(4–5), 319–28.
- 3760 Thompson, M. B., L. A. Lindsay, J. F. Herbert, and C. R. Murphy. (2007). Calcium ATPase
3761 Expression in the Oviducts of the Skink, *Lampropholis guichenoti*. *Comparative*
3762 *Biochemistry and Physiology - A Molecular and Integrative Physiology* **147**(4), 1090–94.
- 3763 Thompson, M. B., and B. K. Speake. (2002). Energy and Nutrient Utilization by Embryonic
3764 Reptiles. *Comparative Biochemistry and Physiology - A Molecular and Integrative*
3765 *Physiology* **133**(3), 529–38.
- 3766 ———. (2003). Energy and nutrient utilisation by embryonic reptiles. *Comparative*
3767 *Biochemistry and Physiology - A Molecular and Integrative Physiology* **133**, 529–538.
- 3768 ———. (2006). A Review of the Evolution of Viviparity in Lizards: Structure, Function and
3769 Physiology of the Placenta. *Journal of Comparative Physiology B: Biochemical, Systemic,*
3770 *and Environmental Physiology* **176**(3), 179–89.
- 3771 Tian, X., J. Gautron, P. Monget, and G. Pascal. (2010). What Makes an Egg Unique? Clues from
3772 Evolutionary Scenarios of Egg-Specific Genes. *Biology of Reproduction* **83**(6), 893–900.

- 3773 Ticconi, C., A. Zicari, A. Belmonte, M. Realacci, C. V. Rao, and E. Piccione. (2007). Pregnancy-
3774 Promoting Actions of HCG in Human Myometrium and Fetal Membranes. *Placenta* **28**,
3775 S137–43.
- 3776 Tilburgs, T., S. A. Scherjon, and F. H.J. Claas. (2010). Major Histocompatibility Complex
3777 (MHC)-Mediated Immune Regulation of Decidual Leukocytes at the Fetal-Maternal
3778 Interface. *Journal of Reproductive Immunology* **85**(1): 58–62.
- 3779 Tinkle, D. W., and J. Whitfield Gibbons. (1977). The Distribution and Evolution of Viviparity in
3780 Reptiles. *Miscellaneous Publications Museum of Zoology University of Michigan* **154**,1–55.
- 3781 Torricelli, M., A. Giovannelli, E. Leucci, G. De Falco, F. M. Reis, A. Imperatore, P. Florio, and
3782 F. Petraglia. (2007). Labor (Term and Preterm) Is Associated with Changes in the Placental
3783 mRNA Expression of Corticotrophin-Releasing Factor. *Reproductive Sciences* **14**(3), 241–
3784 45.
- 3785 Torry, D. S., D. Mukherjea, J. Arroyo, and R. J. Torry. (2003). Expression and Function of
3786 Placenta Growth Factor: Implications for Abnormal Placentation. *Journal of the Society for*
3787 *Gynecologic Investigation* **10**(4), 178–88.
- 3788 Trauth, S. E., and W. R. Fagerberg. (1984). Ultrastructure and Stereology of the Eggshell in
3789 *Cnemidophorus sexlineatus* (Lacertilia: Teiidae). *Copeia* **1984**(4), 826.
- 3790 Trowsdale, J. (2011). The MHC, Disease and Selection. *Immunology Letters* **137**(1–2), 1–8.
- 3791 Trowsdale, J., and A. G. Betz. (2006). Mother’s Little Helpers: Mechanisms of Maternal-Fetal
3792 Tolerance. *Nature Immunology* **7**(3), 241–46.

- 3793 Truong, A. D., Y. Hong, J. Lee, K. Lee, D. Y. Kil, H. S. Lillehoj, and Y. H. Hong. (2018).
3794 Interleukin-34 Regulates Th1 and Th17 Cytokine Production by Activating Multiple
3795 Signaling Pathways through CSF-1R in Chicken Cell Lines. *International Journal of*
3796 *Molecular Sciences* **19**(6), 1–19.
- 3797 Tuan, R., and T. Ono. (1986). Regulation of Extraembryonic Calcium Mobilization by the
3798 Developing Chick Embryo. *Journal of Embryology and Experimental Morphology* **97**, 63–
3799 74.
- 3800 Tuan, R. S., M. J. Carson, J. A. Jozefiak, K. A. Knowles, and B. A. Shotwell. (1986). Calcium-
3801 Transport Function of the Chick Embryonic Chorioallantoic Membrane. I. In Vivo and in
3802 Vitro Characterization. *Journal of Cell Science* **82**, 73–84.
- 3803 Tuan, R. S., and K. A. Knowles. (1984). Calcium-Activated ATPase of the Chick Embryonic
3804 Chorioallantoic Membrane. Identification, Developmental Expression, and Topographic
3805 Relationship with Calcium-Binding Protein. *Journal of Biological Chemistry* **259**(5), 2754–
3806 63.
- 3807 Tuan, R. S., and W. A. Scott. (1977). Calcium Binding Protein of Chorioallantoic Membrane:
3808 Identification and Developmental Expression. *Proceedings of the National Academy of*
3809 *Sciences* **74**(5), 1946–49.
- 3810 Tuan, R. S., W. A. Scott, and Z. A. Cohn. (1978). Calcium-Binding Chorioallantoic Protein of the
3811 Chick Membrane I. Immunohistochemical Localization Enzymatic Dissociation of CAM
3812 into Single Cells Purification of the CaBP. *Journal of Cellular Biology* **77**(3), 743-51.

- 3813 Turin, L., P. Invernizzi, M. Woodcock, F. R. Grati, F. Riva, G. Tribbioli, and G. Laible. (2007).
3814 Bovine Fetal Microchimerism in Normal and Embryo Transfer Pregnancies and Its
3815 Implications for Biotechnology Applications in Cattle. *Biotechnology Journal* **2**(4), 486–91.
- 3816 Tyler, C. (1965). A Study of the Egg Shells of the Sphenisciformes. *Proceedings of the*
3817 *Zoological Society of London* **147**, 1–19.
- 3818 Ugurel, S., V. Rebmann, S. Ferrone, W. Tilgen, H. Grosse-Wilde, and U. Reinhold. (2001).
3819 Soluble Human Leukocyte Antigen–G Serum Level Is Elevated in Melanoma Patients and
3820 Is Further Increased by Interferon- α Immunotherapy. *Cancer: Interdisciplinary*
3821 *International Journal of the American Cancer Society* **92**(2), 369–76.
- 3822 Uller, T., C. Isaksson, and M. Olsson. (2006). Immune Challenge Reduces Reproductive Output
3823 and Growth in a Lizard. *Functional Ecology* **20**(5), 873–79.
- 3824 Uribe, C., H. Folch, R. Enriquez, and G. Moran. (2011). Innate and Adaptive Immunity in
3825 Teleost Fish: A Review. *Veterinari Medicina* **56**(10), 486–503.
- 3826 Van Dyke, J. U., M. C. Brandley, and M. B. Thompson. (2014). The Evolution of Viviparity:
3827 Molecular and Genomic Data from Squamate Reptiles Advance Understanding of Live
3828 Birth in Amniotes. *Reproduction* **147**(1).
- 3829 Vannuccini, S., C. Bocchi, F. M. Severi, J. R. Challis, and F. Petraglia. (2016). Endocrinology of
3830 Human Parturition. *Annales d'Endocrinologie* **77**(2), 105–13.

- 3831 Vieira, S., G. De Perez, and M. Patricia Ramírez-Pinilla. (2007). Invasive Cells in the
3832 Placentome of Andean Populations of *Mabuya*: An Endotheliochorial Contribution to the
3833 Placenta? *Anatomical Record* **290**(12), 1508–18.
- 3834 Visser, J. (1975). Oviparity in Two South African Skinks of the Genus *Mabuya*, with Notes on
3835 Hatching. *Zoologica Africana* **10**(2), 209–13.
- 3836 Vogel, P. (2005). The Current Molecular Phylogeny of Eutherian Mammals Challenges Previous
3837 Interpretations of Placental Evolution. *Placenta* **26**(8–9), 591–96.
- 3838 Vokes, S. A., and P. A. Krieg. (2002). Endoderm Is Required for Vascular Endothelial Tube
3839 Formation, but Not for Angioblast Specification. *Development* **129**(3), 775–85.
- 3840 Vonnahme, K. A., M. E. Wilson, and S. P. Ford. (2002). Conceptus Competition for Uterine
3841 Space: Different Strategies Exhibited by the Meishan and Yorkshire Pig. *Journal of Animal*
3842 *Science* **80**(5), 1311–16.
- 3843 Vonnahme, K. A., M. E. Wilson, and S. P. Ford. (2001). Relationship between Placental
3844 Vascular Endothelial Growth Factor Expression and Placental/Endometrial Vascularity in
3845 the Pig. *Biology of Reproduction* **64**(6), 1821–25.
- 3846 Wagner, G. P., K. Kin, L. Muglia, and M. Pavličev. (2014). Evolution of Mammalian Pregnancy
3847 and the Origin of the Decidual Stromal Cell. *International Journal of Developmental*
3848 *Biology* **58**(2–4), 117–26.

3849 Wasserman, R. H., C. A. Smith, C. M. Smith, M. E. Brindak, C. S. Fullmer, L. Krook, J. T.
3850 Penniston, and R. Kumar. (1991). Immunohistochemical Localization of a Calcium Pump
3851 and Calbindin-D28k in the Oviduct of the Laying Hen. *Histochemistry* **96**(5), 413–18.

3852 Weiss, G., and L. T. Goldsmith. (2001). Relaxin and the Cervix. *The Endocrinology of*
3853 *Parturition* **27**, 105–12.

3854 Wen, Y., W. Fang, L. X. Xiang, R. L. Pan, and J. Z. Shao. (2011). Identification of Treg-like
3855 Cells in Tetraodon: Insight into the Origin of Regulatory T Subsets during Early Vertebrate
3856 Evolution. *Cellular and Molecular Life Sciences* **68**(15), 2615–26.

3857 Whittington, C. M., K. Danastas, G. E. Grau, C. R. Murphy, and M. B. Thompson. (2017).
3858 Expression of VEGF111 and Other VEGF-A Variants in the Rat Uterus Is Correlated with
3859 Stage of Pregnancy. *Journal of Comparative Physiology B: Biochemical, Systemic, and*
3860 *Environmental Physiology* **187**(2), 353–60.

3861 Whittington, C. M., G. E. Grau, C. R. Murphy, and M. B. Thompson. (2015). Unusual
3862 Angiogenic Factor Plays a Role in Lizard Pregnancy but Is Not Unique to Viviparity.
3863 *Journal of Experimental Zoology Part B: Molecular and Developmental Evolution* **324**(2),
3864 152–58.

3865 Whittington, C. M., D. O’Meally, M. K. Laird, K. Belov, M. B. Thompson, and B. M. McAllan.
3866 (2018). Transcriptomic Changes in the Pre-Implantation Uterus Highlight Histotrophic
3867 Nutrition of the Developing Marsupial Embryo. *Scientific Reports* **8**(1), 1–18.

3868 Whittington, C. M., J. U. Van Dyke, S. Q. T. Liang, S. V. Edwards, R. Shine, M. B. Thompson,
3869 C. E. Grueber. (2022) Understanding the evolution of viviparity using intraspecific variation

3870 in reproductive mode and transitional forms of pregnancy. *Biological Reviews* **97**(3), 1179-
3871 1192

3872 Whittle, W. L., A. C. Holloway, S. J. Lye, W. Gibb, and J. R. G. Challis. (2000). Prostaglandin
3873 Production at the Onset of Ovine Parturition Is Regulated by Both Estrogen-Independent
3874 and Estrogen-Dependent Pathways. *Endocrinology* **141**(10), 3783–91.

3875 Wienke, J., L. Brouwers, L. van der Burg, M. Mokry, R. C. Scholman, P. G. J. Nikkels, B. van
3876 Rijn, and F. van Wijk. (2020). Human Tregs at the materno-fetal interface show site-
3877 specific adaptation reminiscent of tumor Tregs. *Journal of Clinical Investigation Insight*
3878 **5**(18), e137926.

3879 Williams, T. D. (2012). *Physiological Adaptations for Breeding in Birds*. Princeton and Oxford:
3880 Princeton University Press.

3881 Wilt, F. H. (1965). Erythropoiesis in the Chick Embryo: The Role of Endoderm. *Science* **147**,
3882 1588–90.

3883 Withanage, G. S. K., K. Sasai, T. Fukata, T. Miyamoto, H. S. Lillehoj, and E. Baba. (2003).
3884 Increased Lymphocyte Subpopulations and Macrophages in the Ovaries and Oviducts of
3885 Laying Hens Infected with Salmonella Enterica Serovar Enteritidis. *Avian Pathology* **32**(6),
3886 583–90.

3887 Wooding, F. B. P., M. P. Ramirez-Pinilla, and A. S. Forhead. (2010). Functional Studies of the
3888 Placenta of the Lizard *Mabuya sp.* (Scincidae) Using Immunocytochemistry. *Placenta*
3889 **31**(8), 675–85.

- 3890 Wootton, R., I. R. McFadyen, and J. E. Cooper. (1977). Measurement of Placental Blood Flow in
3891 the Pig and Its Relation to Placental and Fetal Weight. *Neonatology* **31**(5–6), 333–39.
- 3892 Work, T. M., G. H. Balazs, R. A. Rameyer, S. P. Chang, and J. Berestecky. (2000). Assessing
3893 Humoral and Cell-Mediated Immune Response in Hawaiian Green Turtles, *Chelonia*
3894 *mydas*. *Veterinary Immunology and Immunopathology* **74**(3–4), 179–94.
- 3895 Wray, S., T. Burdyga, D. Noble, K. Noble, L. Borysova, and S. Arrowsmith. (2015). Progress in
3896 Understanding Electro-Mechanical Signalling in the Myometrium. *Acta Physiologica*
3897 **213**(2), 417–31.
- 3898 Wu, C., C. Lv, Y. Wan, X. Li, J. Zhang, J. Li, and Y. Wang. (2019). Arginine Vasotocin
3899 (AVT)/Mesotocin (MT) Receptors in Chickens: Evidence for the Possible Involvement of
3900 AVT-AVPR1 Signaling in the Regulation of Oviposition and Pituitary Prolactin
3901 Expression. *General and Comparative Endocrinology* **281**(Jan), 91–104.
- 3902 Wu, L., L. H. Luo, Y. X. Zhang, Q. Li, B. Xu, G. X. Zhou, H. B. Luan, and Y. S. Liu. (2014).
3903 Alteration of Th17 and Treg Cells in Patients with Unexplained Recurrent Spontaneous
3904 Abortion before and after Lymphocyte Immunization Therapy. *Reproductive Biology and*
3905 *Endocrinology* **12**(1), 1–9.
- 3906 Wu, Q., M. B. Thompson, and C. R. Murphy. (2011). Changing Distribution of Cadherins during
3907 Gestation in the Uterine Epithelium of Lizards. *Journal of Experimental Zoology Part B:*
3908 *Molecular and Developmental Evolution* **316**(6), 440–50.

- 3909 **Xie, H.-X., X.X Liang, W.M. Li, Z.Q. Chen, X.F. Wang, Z.H. Ding, X.M. Zhou, and W.G**
3910 **Du.** (2022). The eggshell-matrix protein gene OC-17 is functionally lost in the viviparous
3911 Chinese crocodile lizard. *Journal of Evolutionary Biology* **35**, 1568–1575.
- 3912 Yagel, S., P. K. Lala, W. A. Powell, and R. F. Casper. (1989). Interleukin-1 Stimulates Human
3913 Chorionic Gonadotropin Secretion by First Trimester Human Trophoblast. *The Journal of*
3914 *Clinical Endocrinology & Metabolism* **68**(5), 992–95.
- 3915 Yang, F., Q. Zheng, and L. Jin. (2019). Dynamic Function and Composition Changes of Immune
3916 Cells During Normal and Pathological Pregnancy at the Maternal-Fetal Interface. *Frontiers*
3917 *in Immunology* **10**, 1–15.
- 3918 Yang, J. H., Z. H. Zhao, J. F. Hou, Z. L. Zhou, Y. F. Deng, and J. J. Dai. (2013). Expression of
3919 TRPV6 and CaBP-D28k in the Egg Shell Gland (Uterus) during the Oviposition Cycle of
3920 the Laying Hen. *British Poultry Science* **54**(3), 398–406.
- 3921 Yang, X., F. Zhao, Q. Han, Y. Dong, J. Lei, C. Yang, Y. Guo, K. Ito, and B. Zhang. (2020).
3922 Transcriptome Analysis in the Shell Gland of Laying Hens Affecting Eggshell Qualities.
3923 *Research Square* 1–19.
- 3924 Yang, Y., D. E. Geraghty, and J. S. Hunt. (1995). Cytokine Regulation of HLA-G Expression in
3925 Human Trophoblast Cell Lines. *Journal of Reproductive Immunology* **29**(3), 179–95.
- 3926 Yie, S. M., L. H. Li, G. M. Li, R. Xiao, and C. L. Librach. (2006). Progesterone Enhances HLA-
3927 G Gene Expression in JEG-3 Choriocarcinoma Cells and Human Cytotrophoblasts in Vitro.
3928 *Human Reproduction* **21**(1), 46–51.

- 3929 Yie, S. M., R. Xiao, and C. L Librach. (2006). Progesterone Regulates HLA-G Gene Expression
3930 through a Novel Progesterone Response Element. *Human Reproduction* **21**(10), 2538–44.
- 3931 Yoshimura, Y., T. Okamoto, and T. Tamura. (1997). Localisation of MHC Class II,
3932 Lymphocytes and Immunoglobulins in the Oviduct of Laying and Moulting Hens. *British*
3933 *Poultry Science* **38**(5), 590–96.
- 3934 Yoshinaga, K. (2008). Review of Factors Essential for Blastocyst Implantation for Their
3935 Modulating Effects on the Maternal Immune System. In *Seminars in Cell & Developmental*
3936 *Biology* **19**, 161–69.
- 3937 Yoshizawa, R. S. (2016). Fetal–Maternal Intra-Action: Politics of New Placental Biologies. *Body*
3938 *and Society* **22**(4), 79–105.
- 3939 Young, I. R., M. B. Renfree, S. Mesiano, G. Shaw, G. Jenkin, and R. Smith. (2011). The
3940 Comparative Physiology of Parturition in Mammals: Hormones and Parturition in
3941 Mammals. *Hormones and Reproduction of Vertebrates* **5**.
- 3942 **Yurchenko A.A, H. Recknagel, and K.R Elmer. (2020)** Chromosome-Level Assembly of the
3943 Common Lizard (*Zootoca vivipara*) Genome. *Genome Biology and Evolution* **12**(11), 1953-
3944 1960
- 3945 Zenclussen, M. L., C. Thuere, N. Ahmad, P. O. Wafula, S. Fest, A. Teles, A. Leber, et al. (2010).
3946 The Persistence of Paternal Antigens in the Maternal Body Is Involved in Regulatory T-Cell
3947 Expansion and Fetal-Maternal Tolerance in Murine Pregnancy. *American Journal of*
3948 *Reproductive Immunology* **63**(3), 200–208.

3949 Zettergren, L. D., and R. T. Cutlan. (1992). Immunoglobulin-containing Cells in Chick Embryo
3950 Urogenital Tissues: A New Site for Early B Lineage Cells in Endothermic Vertebrates.
3951 *Journal of Experimental Zoology* **262**(4), 458–61.

3952 Zhang, J., Y. Wang, C. Zhang, M. Xiong, S. A. Rajput, Y. Liu, and D. Qi. (2019). The
3953 Differences of Gonadal Hormones and Uterine Transcriptome during Shell Calcification of
3954 Hens Laying Hard or Weak-Shelled Eggs. *BMC Genomics* **20**(1), 1–12.

3955 Zimmerman, L. M., L. A. Vogel, and R. M. Bowden. (2010). Commentary: Understanding the
3956 Vertebrate Immune System: Insights from the Reptilian Perspective. *Journal of*
3957 *Experimental Biology* **213**(5), 661–71.

3958 Zimmerman, L. M. (2020). The Reptilian Perspective on Vertebrate Immunity: 10 Years of
3959 Progress. *The Journal of Experimental Biology* **223**.

3960 Zimmerman, L. M., R. M. Bowden, and L. A. Vogel. (2014). A Vertebrate Cytokine Primer for
3961 Eco-Immunologists. *Functional Ecology* **28**(5),1061–73.

3962 **Zimin, A., Zimin, S. V., Shine, R., Avila, L., Bauer, A., Böhm, M., Brown, R., Barki, G., de**
3963 **Oliveira Caetano, G. H., Castro Herrera, F., Chapple, D. G., Chirio, L., Colli, G. R., Doan,**
3964 **T. M., Glaw, F., Grismer, L. L., Itescu, Y., Kraus, F., LeBreton, M. et al., (2022). A global**
3965 **analysis of viviparity in squamates highlights its prevalence in cold climates. *Global***
3966 ***Ecology and Biogeography* **31**(12), 2437–2452.**

3967 Zoccola, D., A. Moya, G. E. Béranger, E. Tambutté, D. Allemand, G. F. Carle, and S. Tambutté.
3968 (2009). Specific Expression of BMP2/4 Ortholog in Biomineralizing Tissues of Corals and
3969 Action on Mouse BMP Receptor. *Marine Biotechnology* **11**(2), 260–69.